

Climate: Opportunities for Improving Engagement Between NOAA and the US National Security Community

Rachael Jonassen and Jeremy Alcorn

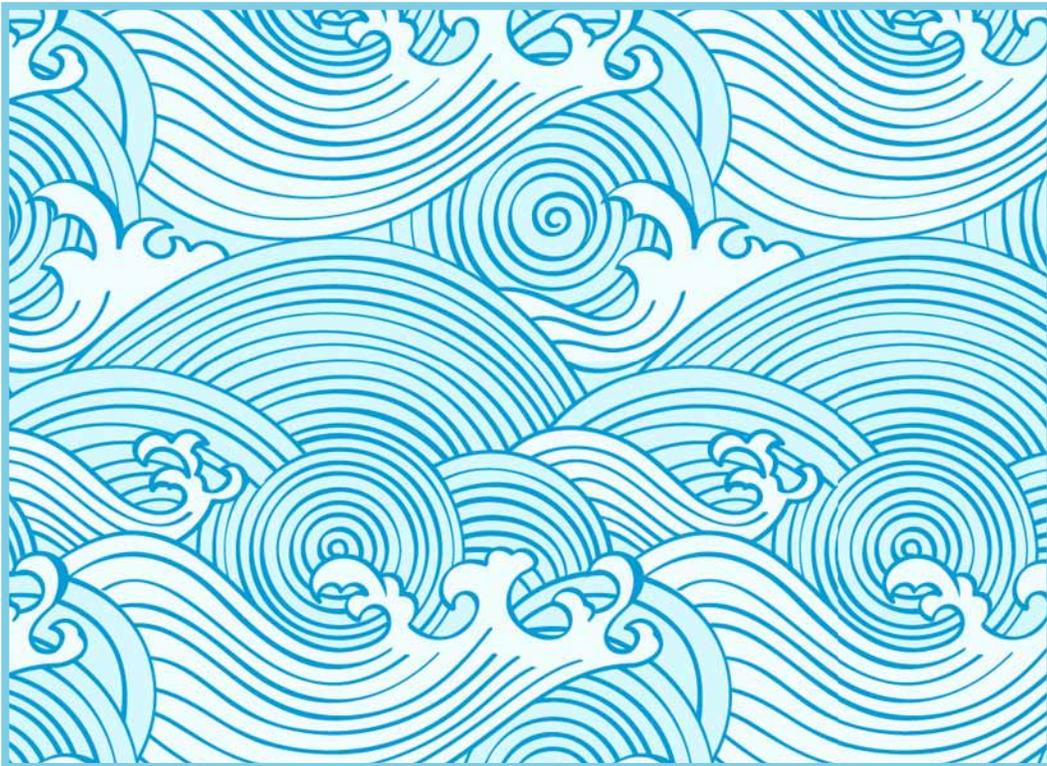


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Conversations with many experts on national defense and climate during and after the workshop clarified issues and focused our attention on the six themes presented here. Dr. Mark Miller of the US Public Health Service (on assignment to the EPA), Mr. Jonathan Herz, and Capt. Ed Pfister of the Department of Health and Human Services provided useful guidance on the role of the public health community. Mr. Paul McCrone of the US Navy Postgraduate School discussed security issues for large data sets. Dr. Adam Parris and Dr. Preston Leftwich pointed us to useful resource material.

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Executive Summary

Six themes emerge from a workshop that discussed potential new climate products and services from the National Oceanic and Atmospheric Administration (NOAA) that could serve needs in the national security community. These themes are the following:

1. Prepare and respond to climate variability and adapt to climate change.
2. Develop climate change predictions endorsed by the federal government.
3. Support national security with NOAA climate products.
4. Move from data access to data application.
5. Sustain cooperation.
6. Consider emerging product areas.

The first theme addresses published statements that imply adaptation to climate variability will help to adapt to climate change. This is not always true. A counterexample is coastal adaptation now in an area that a rising sea level will inundate soon. Greater clarity can help ensure appropriate allocation of adaptation resources. This issue is important to the national defense community both because of its large investment in infrastructure and possible compromise of continuity of operations.

The second theme responds to the lack of any official federal statement of what projected climate changes agencies are obliged to consider in adaptation plans. Such plans are required by laws and regulations that do not stipulate which potential changes to consider. This disconnect could compromise national security planning.

NOAA produces an official forecast of climate for the United States that extends to 1 year in the future. Forecasts are available from NOAA international desks for areas outside the United States. Theme 3 proposes a dialogue on greater

use of NOAA products outside the United States.

New software, new media, and new hardware offer opportunities for NOAA to develop better ways to access data that would nurture greater use. Users also need tools (“apps”) for deeper and more efficient analysis of existing data. Theme 4 shows how NOAA could partner with the national security community to address both of these opportunities.

Effective use of the climate products and services NOAA now provides can be enhanced through a program that facilitates more productive interaction with the national security community. Such interaction can identify, develop, and apply useful products and services. Theme 5 lays the groundwork for effective partnership dealing with the long-term challenges that climate change poses to US national security.

Theme 6 describes several opportunities for early focus. Two are ripe for early action. First, NOAA could use the existing official long-term forecast to develop predictions of active layer thickness in permafrost within Alaska. This information can help protect energy supplies and improve planning for military mobility in Arctic regions. Second, NOAA could work in cooperation with the Naval Oceanographic Office to calculate estimates of tidal range with higher sea level. Such information informs the vulnerability of coastal military installations.

These six opportunities could allow NOAA to better serve the needs of the country and NOAA’s mission to “understand and predict changes in climate.” Together, they could help the national security community respond to challenges from climate variability and climate change.

Effective use of the climate products and services NOAA now provides can be enhanced through a program that facilitates more productive interaction with the national security community.

Introduction

The National Oceanic and Atmospheric Administration (NOAA) sponsors an annual Climate Prediction Applications Science Workshop (CPASW) that brings together climate information users, tool developers, researchers, and providers. These meetings identify state-of-the-art use of climate information and gaps in services. The overall goals of CPASW are to build a community of climate practitioners, discover user needs, assess impacts of climate forecasts on environmental-societal interactions, identify the science potential for meeting these needs, and provide feedback to producers on the usability of existing climate products.

The 10th annual CPASW convened in Miami, FL, on March 13–15, 2012, and featured broad discussions revolving around the integrated theme of “Climate Services for National Security Challenges.” The workshop highlighted national and global uses of data and outlooks from seasonal to decadal scales in applications for a broad array of national security issues: state stability (including border security), international treaties, environmental regulation, resilience of coastal communities, security of natural resources, transportation, health, energy, and food, including agriculture and fisheries. Day two of the meeting was devoted specifically to discussions of national security issues (as defined in this report) related to climate services.

Objective

This report documents and elaborates upon key findings of the meeting that relate specifically to national security issues with a relatively well-defined intended audience (described below). It is not an overall summary of the meeting but does provide a brief synopsis of materials presented to

provide context and a sense of how fully ideas could be vetted and critiqued within the meeting and by participants as this document evolved. All participants were given the opportunity to comment on an early draft of the six key themes included here and multiple NOAA scientists reviewed an early draft of the full report itself. These recommendations do not represent the official position of any federal agency and in no way commit any federal agency to act upon the ideas presented.

Intended Audience

As intended in this report, the national security community includes the 17 intelligence agencies that either operate independently or within other federal organizations; those that direct installation and operational planning within the military services of the Department of Defense (DoD: Army, Navy, Air Force, and Marine Corps); international diplomacy agencies, including the Department of State, the Agency for International Development (USAID), and the Millennium Challenge Corporation (MCC); and internal security organizations, including the Department of Homeland Security (DHS) in its role of protecting border security (including the Coast Guard) and domestic security.

The National Climatic Data Center (NCDC) identifies key stakeholders related to national security—one of 12 sectorial groups that NCDC identifies—as DoD, industry and consultants that help prepare strategy and acquire systems for military services, federal agencies charged with protecting national borders and coasts, and agencies and nongovernmental organizations that are impacted by domestic or international humanitarian crises.¹ This group is consistent with our definition of the intended audience.

¹ NOAA, *NCDC Sectoral Engagement Fact Sheet for National Security*, June 2010, available at <http://www.ncdc.noaa.gov/oa/userengagement/security.pdf>.

In addition to this relatively narrowly defined audience, other federal users of climate data that maintain missions related to national security may find these recommendations of interest. Examples of such agencies include the Department of Transportation (DOT), in regard to national and international transportation networks; the Department of Energy (DOE), in regard to the operation of energy resources; other groups within the Department of Commerce (DOC), in regard to international trade and supply chains; the Department of Health and Human Services (DHHS), in regard to long-term public health challenges; the General Services Administration (GSA), in regard to building assets; the National Aeronautics and Space Administration (NASA), in regard to space assets; the Department of Agriculture (USDA), in regard to global food and fiber assets; the Department of Interior, in regard to global natural resource assets; and the Department of Veterans Affairs, in regard to long-term operations and veteran health.

NOAA audiences are those dealing with climate services within the National Weather Service (NWS); National Environmental Satellite, Data, and Information Service (NESDIS); and Oceanic and Atmospheric Research (OAR). They include the Office of Climate, Water, and Weather Services (OCWSS), Climate Services Division (CSD); the National Centers for Environmental Prediction (NCEP); the Climate Prediction Center (CPC); the Climate Program Office (CPO); NCDC; and the Geophysical Fluid Dynamics Laboratory (GFDL). This report particularly focuses on recommendations to OCWSS/CSD in its roles of validating and documenting climate service requirements, and planning for enhanced and new climate services.

Other groups that may find this report useful include state government personnel with responsibilities in emergency preparedness and planning, corporations that support national security needs of the US government, corporations vital to national security that are considering how climate variability and change could influence their own operations and facilities, non-governmental organizations with a particular interest in national security, and academic and other research organizations that deal in national security issues.

Process

Participants in CPASW 2012² included representatives of NOAA, the Office of the Secretary of Defense, the US Army Corps of Engineers (USACE), the US Navy, the Special Operations Command, intelligence organizations, Oak Ridge National Laboratory, NASA, the US Bureau of Reclamation, states, academics, corporations, and private groups.

An organizing committee² developed meeting goals, structure, and logistics. The meeting was widely advertised in the climate services community, in professional venues, and within the national security community. Following acceptance of abstracts, speakers were given the opportunity to revise abstracts in response to review comments and to focus more clearly on the goals of the meeting. Speakers, particularly those on day two, were to focus their presentations on issues of national security as defined in this report. Designated NOAA staff and the authors of this report recorded presentations and discussions. These notes supported development of the themes. All talks were recorded (audio), and these recordings and the PowerPoint slides from the presentations were available to the authors while developing this report.

² Lists of participants and members of the organizing committee are available at <http://www.rsmas.miami.edu/academics/divisions/marine-affairs-policy/cpasw/>.

Overview of Meeting Results

This section provides a context for the recommendations of this report by describing briefly the overall content and key results of the CPASW 2012 meeting. We focus on ideas that challenge assumptions or suggest new directions.

Speakers at CPASW 2012 split almost evenly between addressing time periods for which NOAA official forecasts already exist (single days to seasons), and time periods for which NOAA official forecasts do not exist (annual to decadal). Since the focus of this report is on the longer time scales at which climate variability and climate change operate and for which NOAA official forecasts do not yet exist, talks having that orientation influence this report more directly.

CPASW 2012 organizers established multiple goals for this workshop:³

1. Build a community of climate practitioners.
2. Discover user needs, and assess the impacts of climate forecasts on environmental-societal interactions.
3. Identify the science potential for meeting these needs.

4. Provide feedback to producers on the usability of existing climate products.

Consistent with goals 2 and 3, the intent of this report is to discuss ways for NOAA to improve climate services for national security. Recognizing the multiple goals of CPASW 2012, not all presentations at the workshop focused on goals 2 and 3. Despite this difference in focus and goals for various speakers, all the presentations offered insights that inform this report (*Table 1*). Roughly half of the presentations and their abstracts⁴ contained suggestions or implications directly related to improved climate products and services. About half of those can be related to the national security focus of this report (as defined in the *Introduction*).

Table 1 lists at least one message from each oral presentation at CPASW 2012 that informed this report. The final column lists those themes each presentation directly helped to shape. *Table 1* is not intended to be a comprehensive statement of the speaker's presentation. In some cases the message listed may have originated during discussion of the presentation. For these reasons the messages of *Table 1* may not reflect the opinion of the author.

³ Goals of CPASW 2012 can be found at <http://www.rsmas.miami.edu/academics/divisions/marine-affairs-policy/cpasw/>.

⁴ Individual abstracts from CPASW 2012 are linked from the agenda, at <http://www.rsmas.miami.edu/academics/divisions/marine-affairs-policy/cpasw/agenda/>.

Table 1. Messages most influential to this report and themes these messages inform. This list follows the order of presentation and no prioritization is implied.

Speaker	Key Message Reflected in This Report	Theme
Holly Hartmann	We need better characterization of adaptation options. Uncertain results are still actionable.	1, 2, 5, 6
John Hall	NCA results can guide internal DoD analysis. Need new policy, user, and science integration.	1, 2, 5, 6
Levi Brekke	Forecast errors can lead to long-term mistrust. We lack forecasts in the 1–5-year time frame.	1, 2, 5
Eduardo Gelcer	Showed a monitor of soil moisture and the expected moisture level for each ENSO phase.	6
Aston Chipanshi	Extreme events greatly reduce the accuracy of forecasts.	1, 2
Shoichiro Miyawaki	We must time forecasts properly for user needs.	1, 5, 6
David Gustafson	Need Integrated Assessment Models for food security. Unverified models are a big problem.	1, 2, 5, 6
John Wiener	High agricultural inputs (e.g., fertilizer, pesticides, herbicides) add to climate vulnerability.	1, 5
Daniel Solís	Hurricanes decrease the short-term productivity of commercial fisheries.	1, 5
Qi Hu	Projects up to 25% decline in corn yield in western part of the US corn belt in late 21st century.	1, 5
S.-Y. Simon Wang	Must include multi-decadal oscillation in forecasts.	2
Jim Westervelt	Some future climates have no modern analog. Are there physiologically meaningful metrics?	2
Robert W. Rooney	Artificial neural network analogs do as well as current forecast.	2
Eric Gordon	Uncertain information can be actionable with appropriate context and sustained engagement.	5
Bonnie Colby	With dry year supply reliability agreements, planning ahead generates substantial savings.	1, 2, 3, 5, 6
Phillip Pasteris	We face new extremes, liabilities; uncertainty at different time scales.	1, 2, 3, 5, 6
Holly Hartmann	Sharing tool ratings; includes toolbox for uncertainty. Need consistency and transparency.	1–6
Keith Eggleston	New products to access data. Adding a GUI would help.	4
Robert Gillies	Produce innovative pest, first freeze, and inversion red days alerts. Gridding needed.	4
Kelly Redmond	Rich regional climate services structure exists, must ensure and portray cohesion.	1–6
Larry Paxton	Cost-effective knowledge access tools. Broad overview of challenges.	4–6
Kelly A. Burks-Copes	Great example of impacts assessment at high resolution; coastal hazards and sea level rise.	1, 2, 5, 6
John White	Building partnerships and stability through multi-scale climate services applied at village level.	2, 5, 6
Caspar Ammann	Bring knowledge with information; shift access: analysis. Preserve boundary conditions.	4–6
Jeremy Alcorn	Analysis requires averages and worst-case scenarios.	1, 5, 6
John Weatherly	Linking models for applications in military contexts. Downscaling is necessary.	3, 5, 6
Steve Tanner	Examples of military readiness in Afghanistan, Huntsville, and the Arctic.	3, 5, 6
Laurence Kalkstein	Heat health warning systems need to be improved, use of a better model.	6
Gina Henderson	Must couple earth system science and human systems knowledge.	5
Rachael Jonassen	Seasonal forecasts of permafrost ALT should be considered now.	6
Stamatia Voulgaraki	Interactions of crop production, resource use, and environmental impact w/climate change.	1
Amor Ines	To improve yield prediction requires merging monitored and forecast climate.	3, 6
Mike Halpert	For CPC, national security = food security; won't add GCMs soon, needs twice the budget.	2
Chris Landsea	Hurricane: 3% peak wind increase; decreased frequency; may decline soon due to AMO.	1
Gino Marinucci	Focus on 25–50-year horizon. Can we prioritize and sequence early and later actions?	1, 2, 5, 6
Cary Lopez	Is there any difference in the health effects of climate variability versus climate change?	1, 5, 6
Antarpreet Jutla	Seasonal forecasts alert health community to focus resources, water, and sanitation.	1
David Green	Climate links three one-health areas. How good does information on risk level need to be?	2, 5
Derek Willis	How does the framing of forecasts affect the decisions of policy makers?	2, 5
David Quesada	Asthma in Miami: increase and seasonal pattern, weather/air quality, WeatherBug network.	1, 5, 6
Caitlin Simpson	RISA is a transdisciplinary 5-year program that sets a model for cooperation.	5
Keith Ingram	Use no-regrets approach. Combine conveying risk with known and unknowns.	1, 2
Kristen Averyt	Incorporating uncertainty in planning.	1, 5
Tamara Wall	How decision makers use climate information.	5
Norman Brewer	Assessment is a process, merge multiple methods, not just survey.	5
Jenny Dissen	Displacement and migration chart, 2006–2011 most of Syria had drought.	1, 5
Andrew P. Jones	Key elements of games help learning process.	5
William H. Swartz	Need for actionable information 1–30 years out requires a new type of collaboration.	1, 2
Steve Ansari	NCDC tools facilitate data access and display.	4
Jessica Bolson	Need to educate water managers on available data and tools, and climate change literature.	4, 5
Fiona Horsfall	Can we extend Local Climate Analysis Tool for national security applications?	4, 5
Adam Parris	Usable science defined in 1990 Global Change Research Act. Push, pull, and push-pull.	1, 5
Malgosia Madajewicz	Rigorous evaluations, as used with social programs, help design effective adaptation.	1, 5
Tjerk Wardenaar	Design projects with overlapping membership to improve flow of knowledge.	1, 5

NCA = National Climate Assessment; ENSO = El Niño/Southern Oscillation; GUI = graphical user interface; ALT = active layer thickness; GCM = general circulation models AMO = Atlantic multidecadal oscillation; RISA = Regional Integrated Sciences and Assessments.

The multiple perspectives offered in presentations and related discussions have done much to clarify issues surrounding the themes we present in the remainder of the report. In light of the broad input from participants as reflected in the various ideas compiled above, we propose that future interactions between NOAA and the national security community focus on the following six themes:

1. Prepare and respond to climate variability and adapt to climate change.
2. Develop climate change predictions endorsed by the federal government.
3. Support national security with NOAA climate products.
4. Move from data access to data application
5. Sustain cooperation.
6. Consider emerging product areas (including a. permafrost and b. tidal extremes)

We discuss each of these themes in the following sections. *Table 2* identifies various organizations within NOAA, the national security community, and other agencies of the US government that might be appropriate to include in follow-up discussions and implementation of the recommendations of this report. Exclusion from this list of any agency that might offer assistance and expertise is inadvertent, and we expect additional groups will be identified and included as the efforts develop.

Table 2. Preliminary list of organizations whose participation could enhance efforts to address the six themes of this report.

Organization	Theme							
	1	2	3	4	5	6	6a	6b
NOAA CLIMATE SERVICE PROVIDERS								
GFDL, Climate Change, Variability and Prediction Group	x	x			x	x		x
Marine Fisheries Service	x				x	x	x	
National Climate Prediction and Projection Pilot Platform		x						
National Integrated Drought Information System	x		x		x	x		
National Weather Service (NWS), Climate Prediction Center (CPC)	x	x	x	x	x	x		x
NESDIS, National Climatic Data Center	x			x	x	x	x	x
National Ocean Service (NOS) Center for Operational Oceanographic Products and Services	x				x	x		x
NOS, Coastal Services Center	x			x	x	x	x	
NWS, Climate Services Division (CSD)	x		x	x	x	x		x
OAR, Climate Program Office	x	x	x	x	x	x	x	x
OAR, Earth System Research Laboratory	x	x	x	x	x	x		x
NOAA's Paleoclimatology Program	x							
NOAA's Regional Climate Centers	x			x	x	x	x	x
DEPARTMENT OF DEFENSE CLIMATE USERS								
DoD, Office of Secretary of Defense (Policy)	x	x			x			
DoD, Office of Secretary of Defense (Installations & Environment)	x				x			x
DoD, Strategic Environmental Research and Development Program	x	x		x	x	x	x	x
Army, Headquarters	x				x			

Opportunities to Expand NOAA Support for US National Security

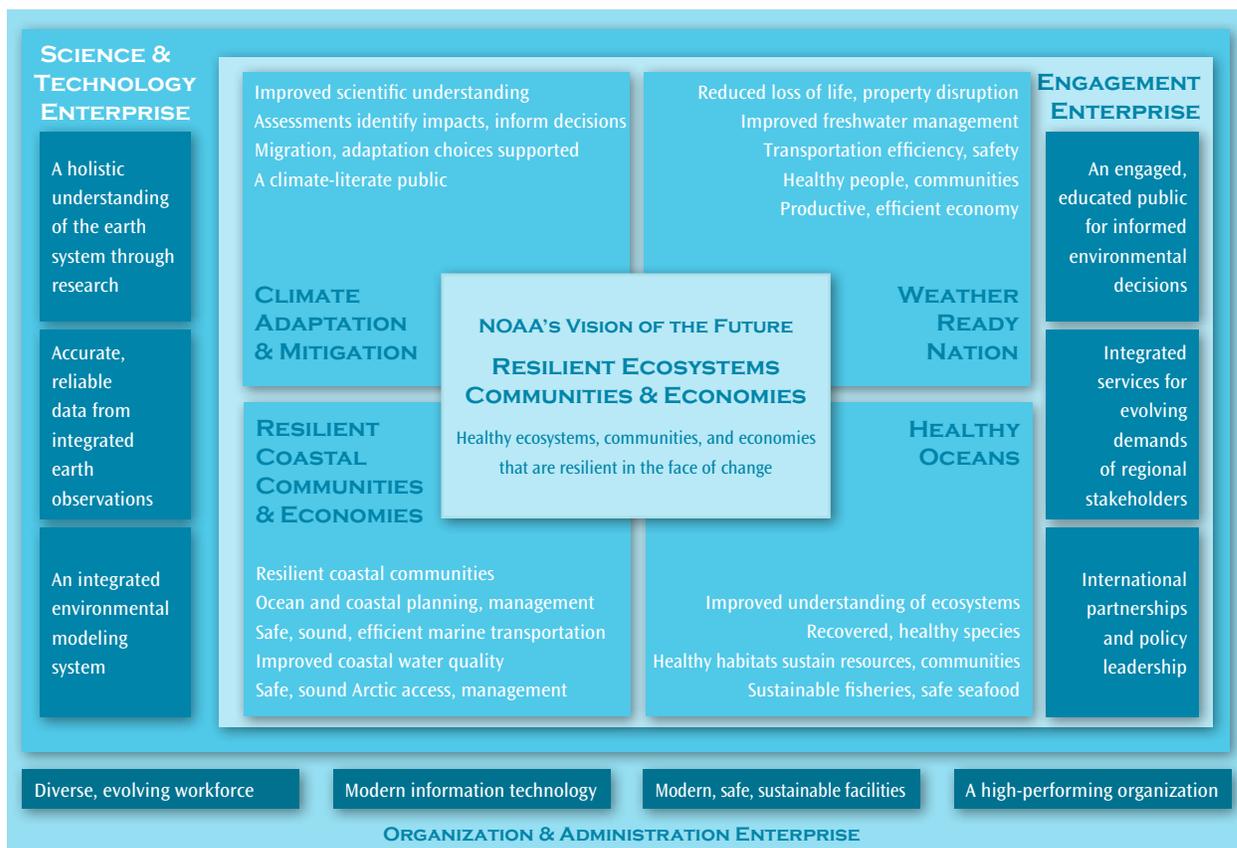
Organization	Theme								
	1	2	3	4	5	6	6a	6b	
Air Force, Headquarters	x				x				
Navy, Task Force Climate Change (TFCC)	x	x	x	x	x			x	
US Army Corps of Engineers (USACE), including users of tide data	x	x	x	x	x	x	x	x	
Military Academy						x			
Army War College	x				x				
Air Force Academy	x								
Naval Academy	x							x	
US Northern Command (USNORTHCOM)		x	x		x	x	x	x	
US Africa Command (AFRICOM), Knowledge Development Division		x	x		x	x		x	
US Southern Command (USSOUTHCOM)		x	x		x	x		x	
US Special Operations Command (USSOCOM)		x	x	x	x	x		x	
US Army Special Operations Command (USASOC)	x	x	x	x	x	x	x	x	
Navy, Naval Facilities Engineering Command (NAVFAC)	x	x	x		x	x		x	
Air Force (USAF), 14th Weather Squadron	x	x	x	x	x	x			
Air Force Weather Agency	x	x	x	x	x	x			
Cold Regions Research and Engineering Laboratory (CRREL)							x		
OTHER COLLABORATORS									
Agency for International Development, Famine Early Warning Systems Network (FEWS NET)			x						
Alaska State Climatologist							x		
American Association of State Climatologists	x			x	x	x	x	x	
Arctic Research Commission							x		
Centers for Disease Control and Prevention, Climate Change Program	x			x	x	x			
Department of Agriculture	x			x	x	x			
Department of Energy, Oak Ridge National Laboratory			x						
Department of Health and Human Services	x	x			x	x			
Department of Interior, Bureau of Reclamation	x			x	x	x	x	x	
Department of State	x	x	x	x	x	x	x	x	
Department of Transportation	x	x	x	x	x	x	x	x	
Department of Veterans Affairs	x	x	x	x	x	x	x	x	
Department of Homeland Security (incl. Federal Emergency Management Agency)								x	
General Services Administration	x	x	x	x	x	x	x	x	
US Global Change Research Program (USGCRP), National Climate Assessment	x	x		x		x		x	
Interagency Arctic Research Policy Committee							x		
International Research Institute for Climate and Society	x		x	x	x	x		x	
Millennium Challenge Corporation	x	x			x			x	
National Aeronautics and Space Administration, FEWS-NET			x						
Office of Science and Technology Policy	x	x	x	x	x	x	x	x	
University Corporation for Atmospheric Research (UCAR)	x	x	x	x	x	x	x	x	

Both NOAA overall⁵ and NWS in particular⁶ identify strategic goals for the organization that dictate the assignment of resources and focus of personnel. *Figure 1* summarizes the most current NOAA goals. At the end of our discussion of each theme, we note how that theme supports existing goals and objectives of NOAA and NWS. Implementing the six themes presented here will help NOAA and NWS achieve current goals.

In general, the recommended actions under all six themes are consistent with NWS Strategic Goal 3, Objective 1: Enhance NWS services to support development and delivery of NOAA climate ser-

vices, and with its call for “closer collaboration with ... federal government agencies to provide more integrated, usable, and relevant information and services,” as well as its call for “helping other organizations and agencies understand and better use the information NWS already produces.”

Appendix A lists individuals who provided review comments to an earlier draft of this report. The authors thank these reviewers for their important and thoughtful input, which helped us to improve the final product.



Source: http://www.ppi.noaa.gov/wp-content/uploads/NOAA_NGSP.pdf.

Figure 1. NOAA's Next Generation Strategic Plan, goals and objectives.

⁵ NOAA's Next Generation Strategic Plan, December 2010, available at http://www.ppi.noaa.gov/wp-content/uploads/NOAA_NGSP.pdf.

⁶ NOAA NWS, NOAA's National Weather Service Strategic Plan 2011 (June 2011), available at http://www.nws.noaa.gov/com/weatherreadynation/files/strategic_plan.pdf.

Theme 1—Prepare and Respond to Climate Variability and Adapt to Climate Change

Challenge

Preparing and responding to climate variability is not always synonymous with adapting to climate change. The climate services community largely recognizes the temporal- and capability-related distinctions. However, this nuance isn't necessarily obvious to or appreciated by the broader national security community. Furthermore, the climate services available to inform the former are more often production quality 1–12 month predictive products, whereas those for the latter are research-oriented projections (1–100 years). These distinctions challenge effective communication with national security

practitioners, introduce the possibility of inappropriate actions, change the cost-benefit calculus, and complicate efforts to match climate services to mission needs.

Context within meeting

Meeting participants discussed the differences between preparing for and responding to climate variability and adaptation to climate change as two different but overlapping topics (Figure 2), yet such an understanding is not universal. Some may casually state that they are equivalent as a means to encourage those who are reticent to expend resources on the latter but willing to consider the former. Discussants recommended that it is important to ensure that the national security community understands and acts on the differences and commonalities between the two challenges.

Preparing and responding to climate variability is not always synonymous with adapting to climate change.

Importance to national security

Preparation for and responding to climate variability might be equated to “rearranging the deck chairs of the Titanic” if climate change repurposes an area. For example, those who plan military installations at elevations near to sea level today may find themselves expending large sums to protect those installations in the future, even though it may have been as useful operationally and far more cost-effective to locate the installation elsewhere in recognition of a projected sea level rise.

In some instances, preparing for and responding to climate variability might indeed help to adapt to climate change. In other cases, the actions needed to adapt to climate change may be very different from the actions to prepare for and respond to climate variability. Moreover, preparing for the one may in fact countervail one's adaptation to the other, as in the example of sea level rise cited above. It is extremely challenging for any group to correctly envision, and prepare for, the likely consequences of climate change, but failure to do so may lead to significantly larger challenges in the future.

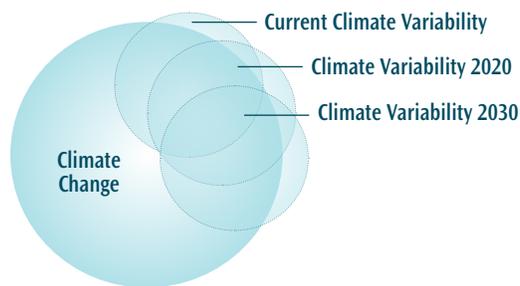


Figure 2. Venn diagram illustrating the logical difference between actions needed to prepare for and respond to current climate variability and the actions needed to adapt to climate change. Also shown is one potential way the actions needed to prepare for and respond to climate variability may change (2020, 2030) as the global climate changes.

Context in literature

Glantz⁷ was an early proponent of distinguishing between actions needed to prepare for and respond to current climate variability and the

range of actions needed to adapt to climate change. This distinction becomes more important if the climate signal is not stationary, which mounting evidence suggests.⁸

The World Climate Research Programme and the National Research Council identified three “categories of

climate variability and change: seasonal to interannual variability, decadal to century climate variability, and changes in climate induced by human activities, such as emission of greenhouse gases. Each is associated with different types of users or decision makers and with different types of needs and products.”⁹

The NRC notes that “there are important differences between coping with variability and planning for climate change.”

Reviewing guidance on water resources adaptation to climate variability, the National Research Council (NRC) identified the need to “distinguish clearly between discussions of climate change and of variability.”¹⁰ More broadly, it notes that although past examples of coping with climate variability may inform efforts to adapt to climate change, “these examples alone may not be sufficient for coping with future climate change.” The NRC concludes, “In the long term, adaptation to climate change calls for a new paradigm that takes into account a range of possible future climate conditions and associated changes in human and natural systems instead of managing our resources based on previous experience and the historical range and variability of climate.” The NRC notes that “there are important differences between coping with variability and planning for climate change” and lists some of those differences, such as the unprecedented pace of change, the potential for abrupt change, or change that takes the earth system out of the range of past experience. “Past adaptations to climate variability in the Gulf Coast environment and its resources have provided many benefits; but, as time has passed, many of these actions have constrained present options.” The NRC also expresses concern that many of the methods of adapting to climate variability in the past have not been evaluated for their potential for adaptation to climate change in the future. “Climate change is likely to pose challenges beyond those that have been addressed in the past as adaptations to climate variability.”¹¹

⁷ M. H. Glantz, *Climate Affairs: A Primer* (Island Press, 2003). See particularly “Climate Behavior,” p. 22 ff.

⁸ P. C. Milly et al., “Stationarity Is Dead: Whither Water Management?” *Science* 319 (2008), pp. 573–4.

⁹ National Research Council, *A Climate Services Vision: First Steps toward the Future* (National Academies Press, 2001).

¹⁰ National Research Council, *Review of CCSP Draft Synthesis and Assessment Product 5.3: Decision-Support Experiments and Evaluations Using Seasonal to Interannual Forecasts and Observational Data* (Washington, DC: The National Academies Press, 2008), available at http://www.nap.edu/openbook.php?record_id=12087&page=2.

¹¹ National Research Council, *Adapting to the Impacts of Climate Change* (Washington, D.C.: The National Academies Press, 2010).

Most recently, the Intergovernmental Panel on Climate Change (IPCC) concludes, “Some strategies for effectively managing risks and adapting to climate change involve adjustments to current activities. Others require transformation or fundamental change.”¹²

Confusion in the literature is understandable. Article 1 of the United Nations Framework Convention on Climate Change (UNFCCC, as ratified by the United States) defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes. More recently the IPCC Fourth Assessment Report (AR4) provided a broader definition of climate change that includes non-anthropogenic factors. The IPCC AR4 Working Group One definitions of climate change and climate variability differ in that the former is defined as a change that persists decades or longer.¹⁴ AR3¹⁵ and AR4 are consistent in these definitions. Most recently, the IPCC expanded the definition

of climate variability to include variability due to anthropogenic factors.¹⁶

An example of the challenge of terminology comes from the Food and Agricultural Administration (FAO) *Guidance for Bangladesh*¹⁷ developed in 2007. This drew upon definitions from the IPCC AR3 Synthesis Report¹⁸ and address climate change and variability with the goal to provide a “reference and training guide for building the capacity of agricultural extension workers and development professionals to deal with climate change impacts and adaptation.” The guidance speaks of long-range climate forecasts ranging up to seasons. Thus, the potential changes over decades are not incorporated in the guidance, and users are encouraged to deal with the climate variability known from the observational record. For example, guidance includes the option to create a pond on farmed land but does not discuss the possibility that sea level rise may mean the land is totally inundated. Bangladesh is the country most vulnerable to sea level rise; 15 percent of its population could be directly impacted (*Figure 3*).¹⁹

Status of federal and other efforts

The USAID guidance for vulnerability assessment for climate change and variability conflates the

¹² IPCC, *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2012), available at <http://www.ipcc-wg2.gov/SREX/>.

¹³ *United Nations Framework Convention on Climate Change* (United Nations, 1992), available at <http://unfccc.int/resource/docs/convkp/conveng.pdf>.

¹⁴ IPCC, “Glossary,” in A.P.M. Baede (ed.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2007).

¹⁵ IPCC, *Third Assessment Report: Climate Change 2001*, available at http://www.grida.no/publications/other/ipcc_tar/.

¹⁶ IPCC, *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2012), available at <http://www.ipcc-wg2.gov/SREX/>.

¹⁷ Food and Agriculture Organization of the United Nations, Asian Disaster Preparedness Center, *Climate Variability and Change: Adaptation to Drought in Bangladesh* (Rome, 2007), available at <ftp://ftp.fao.org/docrep/fao/010/a1247e/a1247e00.pdf>.

¹⁸ IPCC, *Climate change 2001: Synthesis report. Contribution of Working Group I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2001).



Source: <http://www.unep.org/dewa/vitalwater/article146.html>

Figure 3. Impact of a 1-meter sea level rise on Bangladesh.

two and explicitly states, “Much of the experience of addressing current climate variability can be applied to longer-term climate impacts.” USAID claims that “Historical records may serve as a proxy for projections of future change—if something has happened before, it could happen again” (p. 11) and recommends that “emphasis should be on finding measures that increase resilience to climate change, but still make sense under the current climate.” Its six-step process (its Exhibit 6) is advertised as a method for adapting to climate change (not variability), but it speaks to variability in some steps and only change in others. The guidance table of contents mentions

only climate change, not climate variability. Most sentences that refer to climate variability also refer to climate change, giving the impression they do not require separate consideration. Thus, the two seem to be conflated in many places, and coverage is confusing. On the other hand, its Rule 2 properly warns that climate change could introduce new risks.²⁰

The Adaptation Plan for the State of California makes an instructive distinction between hazards-based and vulnerability-based approaches that can clarify why some studies tend to emphasize the utility of considering climate variability when discussing adaptation to climate change. A vulnerability-based approach (such as employed by USAID as discussed above) tends to emphasize vulnerabilities identified by reference to past experience. A hazards-based approach tends to consider challenges identified based on projections of current conditions into the future.²¹ Both are useful, but it is important to understand how a vulnerability-based approach could lead to conflation and must be further informed by a hazards-based approach. Uncertainty in vulnerabilities identified from past experience is not well understood. Uncertainty in projections cannot be validated and, thus, may lead to unreliable guidance.

The Federal Highway Administration adaptation planning followed a model like that advocated by the State of California. It first focused on assessing hazards based on model projections under a variety of scenarios using multiple modeling approaches.²² More recently it has provided

¹⁹ Philippe Rekacewicz, United Nations Environment Programme/GRID-Arendal, “Potential Impact of Sea-Level Rise on Bangladesh” (2006), available at http://www.grida.no/graphicslib/detail/potential-impact-of-sea-level-rise-on-bangladesh_a823.

²⁰ USAID, *Adapting to Climate Variability and Change: A Guidance Manual for Development Planning* (August 2007), available at <http://quest.usaid.gov/node/2002>.

²¹ California Natural Resources Agency, *2009 California Climate Adaptation Strategy* (2009), available at http://masgc.org/climate/cop/Documents/CA_CAS2009.pdf.

²² US Department of Transportation, Federal Highway Administration, “Regional Climate Change Effects: Useful Information for Transportation Agencies,” at http://www.fhwa.dot.gov/environment/climate_change/adaptation/resources_and_publications/climate_effects/effects07.cfm.

guidance to states on assessing vulnerability and identifying critical infrastructure for more detailed focus.²³ In contrast, the US Forest Service offers a web-based instruction guide for land managers, the Climate Change Resource Center, yet headings refer to climate variability even as the resources referenced deal with climate change.²⁴

Some confusion in treatment among federal agencies may arise from the Council on Environmental Quality (CEQ). The CEQ 2011 Adaptation Program Update Report almost universally refers to climate change in every sentence where climate variability is mentioned, except when referring to a current effort by NOAA to alert federal agencies of existing climate variability in coastal settings. Even in the definition of vulnerability the CEQ states that climate change includes climate variability (and extremes). While it is true that a changed climate will be variable, to imply that current climate variability is a subset of climate change may confuse readers.²⁵ Overall, the CEQ report fails to differentiate adaptation challenges of climate variability from those that will arise from climate change. Yet climate variability is never mentioned in the CEQ Policy Goals, Guiding Principles, or in the implementing instructions.²⁶

Two different types of climate information are appropriate for these different scales, and the appropriate products come from different sources and communities. NOAA's National Weather Service Climate Prediction Center (CPC) delivers

information—operational climate forecasts from 2 weeks to 1 year—about some types of climate variability (predictions). NOAA's Geophysical Fluid Dynamics Laboratory delivers information about long-term climate change (projections).

Recommended actions

To the extent that individuals or groups within the national security community inadvertently conflate the challenges of adapting to current climate variability and long-term climate change, NOAA climate scientists can help clarify the differences.

Proper response to the challenge in each time scale requires interactions with the right community, use of the appropriate product, and proper training in the use of products. Knowledge for adaptation to climate variability, whether known from the instrumental record or forecast by CPC, may come from experts in many fields, including civil engineering, public health, and water resources. Adapting to the challenges of climate change may require additional expertise, such as that available among paleoclimatologists, who may have perspective on actual characteristics of climates significantly different from those we observe today.

We suggest addressing the climate variability and climate change awareness challenge and its implications for adaptation through four complementary activities:

Knowledge for adaptation to climate variability...may come from experts in many fields, including civil engineering, public health, and water resources.

²³ US Department of Transportation, Federal Highway Administration, "Assessing Criticality in Transportation Adaptation Planning," at http://www.fhwa.dot.gov/environment/climate_change/adaptation/resources_and_publications/assessing_criticality/index.cfm.

²⁴ US Forest Service, Climate Change Resource Center, "Adapting to Climate Change—A Short Course for Land Managers," at http://www.fs.fed.us/ccrc/hjar/index_st.html.

²⁵ White House, Council on Environmental Quality, *Federal Actions for a Climate Resilient Nation, Progress Report of the Inter-agency Climate Change Adaptation Task Force*, October 28, 2011.

²⁶ White House, Council On Environmental Quality, *Instructions for Implementing Climate Change Adaptation Planning in Accordance With Executive Order 13514, "Federal Leadership In Environmental, Energy, And Economic Performance,"* March 4, 2011.

1. National security technical collaborators should identify relevant guidance, programs, and project documents related to climate change and climate variability. Climate adaptation experts should review existing and proposed national security guidance such as the Quadrennial Defense Review (QDR),²⁷ advisory documents such as from the Defense Science Board (DSB),²⁸ project descriptions, and products discussing response to climate variability and climate change. Do they make the distinction clear? Do they reflect the correct understanding of these? Teams with appropriate membership should suggest revisions as needed.
2. Develop a training and education plan to ensure that practitioners are properly informed on this issue. Identify practitioners who focus on climate variability, climate change, or both. Be sure they are linked to the appropriate resources.
3. Engage national security policy and program practitioners to solicit comments and counter-examples where actions are not complementary.
4. Inform the community on the differences between adapting to climate change and adapting to climate variability. Create a clear model of these differences that is accessible to the relevant communities. Seek feedback, input on relevant adaptation actions for both, and examples of products used in such activities. Develop a concise brochure on adapting to climate variability and climate change, including definitions and examples. This education should address the differences in uncertainty and appropriate risk analysis approaches. Use

this product to engage national security practitioners.

Relation to NOAA and NWS strategic planning

NOAA's Strategic Plan identifies climate adaptation as a key element of its first strategic goal. The actions we recommend are consistent with and support all four objectives under that strategic goal—particularly objective 3: “adaptation choices supported by sustained, reliable, and timely climate services”—and with the enterprise-wide capabilities goal to support “improved capacity to make scientifically informed environmental decisions.” The National Weather Service Strategic Goal 3 seeks to “Enhance climate services to help communities, businesses, and governments understand and adapt to climate-related risks.” Our recommendations are consistent with that strategic goal also.

Payoff of improvements

This theme sets the stage for the remaining themes, because it addresses the two disparate climate time scales we encounter in supporting the national defense community. Climate variability information is useful and necessary but not sufficient. In particular, climate change is a different phenomenon and operates at a different time scale.

Agencies and governments that clearly recognize this difference and that plan and act accordingly will be less likely to be taken by surprise by the enormous dislocations of political, economic, and social systems projected in climate change and may be more effective in responding to the effects of climate variability.

²⁷ Department of Defense, *Quadrennial Defense Review Report* (Washington, DC: DoD, February 2010).

²⁸ Defense Science Board, *Trends and Implications of Climate Change for National and International Security*, October 2011.

Theme 2—Develop Climate Change Predictions Endorsed by the Federal Government

Challenge

The 2010 QDR requires that DoD consider possible climate change futures. National security leaders have called for “plausible” climate change products, particularly those useful for strategic planning and military capability assessments.²⁹

Multiple sources provide climate change projections, so federal agencies, including DoD, require technical assistance in evaluating them. Neither time nor resources allow agencies to consider all projections, and some should not be considered. The proper use of such uncertain information requires careful evaluation and application of appropriate scientific knowledge.

Context within the meeting

CPASW participants focused on the acute need for authoritative, sanctioned climate projections for analysis, policy, and planning. Concurrently, federal agencies must consider legislation, executive orders, and other directives in anticipating the effects of climate change on their installations and operations.

Participants noted that there are currently no federally approved scenarios or projections, though some will come from the National Climate Assessment (NCA), due in 2013.

Various presentations demonstrated a tension within the climate services community between supporting climate future projections, which are now considered “research products,” and the skillful production of more “traditional” predictive products. Participants also cautioned that unverified climate change projec-

Shifting consensus on the “best” projections can lead to discontinuities in plans and inefficient allocation of adaptation resources.

Importance to national security

Climate change will directly impact national security by

1. disrupting DoD’s built and natural infrastructure that is the basis for sustaining military readiness; coastal/island installations are of particular concern given their number, critical missions, exposure, potential sensitivity, and unknown adaptive capacity;
2. affecting the cost and availability of energy required by DoD to operate due to mitigation, climate impacts, or adaptation efforts;
3. destabilizing regions of the world unable to adequately respond to the impacts of climate change; and
4. increasing the frequency and intensity of humanitarian crises due to natural disasters.³⁰

With multiple climate change projections, different groups could use different projections and produce inconsistent policy, programs, and actions. Shifting consensus on the “best” projections can lead to discontinuities in plans and inefficient allocation of adaptation resources.

²⁹ Lauren Morello cites retired Major General Richard Engel of the National Intelligence Council (NIC) and Rear Admiral David Titley of the Navy’s Task Force Climate Change in “Defense Experts Want More Explicit Climate Models,” *New York Times*, June 24, 2010.

³⁰ J. Hall, “Department of Defense and Climate Change: Role of R&D and the National Climate Assessment,” Session 1, National Security Keynote Session, 10th Climate Prediction Applications Workshop, Miami, FL, March 13–15, 2012, slide 12.

tions should not drive policy development and investments.

Context in the literature

A panel of the National Academy of Public Administration noted that “NOAA does not currently have an organizational component that is routinely and exclusively devoted to generating long term (beyond a two-year period) climate predictions. ... Our assessment indicated a strong external demand for predictions and projections for the decadal, multi-decadal and even centennial timeframes at the appropriate scale.” The panel recommended that NOAA create such a unit.³¹

Climate scientists are reluctant to present climate change scenarios as predictions. Instead they are termed projections.³² The distinction is important and reflects the uncertainty and inability to provide classic measures of skill for these model analyses.³³

Solutions of general circulation models (GCMs) for a variety of scenarios represent many diverse possible futures (projections).³⁴ Scenarios differ in scientific vintage, and inter-model compari-

sons reveal differences in accuracy and fidelity in representing physical processes. Researchers question whether such models are useful for real-life applications,³⁵ especially when computed at space³⁶ and time³⁷ scales relevant to climate change. Research on these issues continues.³⁸

The NCA (to be completed in 2013) uses six principal scenario groups and 40 scenarios from the IPCC Special Report on Emission Scenarios (SRES).^{39,40} NCA 2013 will use models from phase 3 of the Coupled Model Intercomparison Project (CMIP3), which were developed for the Fourth Assessment Report (AR4) of the IPCC. CMIP3 included 21 models running 12 different experiments from up to 18 different models each. Some groups produced multiple realizations (up to 9) of a single experiment based on A2 and B1 scenarios from SRES.

The 2013 NCA also will provide higher resolution results for the United States from downscaling models. The Regional Climate Change Assessment Program (RCCAP) is now using one emissions scenario (A2 from SRES) with five global models and six regional models to downscale global results to North America. These model

³¹ “Building Strong for Tomorrow: NOAA Climate Service,” A Report by a Panel of the National Academy of Public Administration for the U.S. Department of Commerce, National Oceanic and Atmospheric Administration and the U.S. Congress, September 13, 2010.

³² M. MacCracken, “Prediction versus Projection—Forecast versus Possibility,” *WeatherZine*, Edition Number 26, February 2001, Guest Editorial. <http://sciencepolicy.colorado.edu/zine/archives/1-29/26/guest.html>.

³³ M. C. Lemos and R. B. Rood, “Climate projections and their impact on policy and practice,” *WIREs Climate Change*, v.1, September/October 2010. <http://wires.wiley.com/WileyCDA/WiresJournal/wisId-WCC.html>.

³⁴ Here we distinguish between climate predictions and climate projections. For more details on the distinction see the Glossary. For examples of current NOAA predictions, see Theme 3.

³⁵ Z. W. Kundzewicz and E. Z. Stakhiv, “Are Climate Models ‘Ready for Prime Time’ in Water Resources Management Applications, or Is More Research Needed?” Editorial, *Hydrological Sciences Journal* 55:7, 1085–1089.

³⁶ R. A. Pielke Sr. and R.L. Wilby, “Regional Climate Downscaling—What’s the Point?” *Eos Transactions of the American Geophysical Union*, 93:5 (2012), 52–53.

³⁷ G. A. Meehl et al., “Decadal Prediction: Can It Be Skillful?” *Bulletin of the American Meteorological Society*, 90:10 (2009), 1467–1485.

³⁸ National Science Foundation, “Decadal and Regional Climate Prediction Using Earth System Models (EaSM),” Program Solicitation 12-522, at <http://www.nsf.gov/pubs/2012/nsf12522/nsf12522.htm>.

³⁹ A.C. Janetos et al., *Modeling and Scaling Issues in the National Climate Assessment*, 2011

⁴⁰ N. Nakicenovic et al., *Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2000), available at <http://www.grida.no/climate/ipcc/emission/index.htm>.

results will represent the best high-resolution analyses available.

Since the last NCA was published,⁴¹ new emission scenarios and model analyses have been designed for AR5, which is due to be released in 2014. AR5 will use four Representative Concentration Pathways (RCPs) corresponding to different levels of radiative forcing through 2100. CMIP5 results for AR5 derive from 42 models submitted by 21 groups from 14 countries.

Thus, the national security community can access model results from three major efforts: NAS 2013/SRES A2 and B1/CMIP3, NAS 2013/SRES A2/RCCAP, and AR5/RCP/CMIP5. The first provides over 400 results, RCCAP offers 30, and AR5 will provide at least 400.

Status of federal and other efforts

The National Security Strategy (NSS) states that the United States “will therefore confront climate change based upon clear guidance from the science, and in cooperation with all nations.” The NSS identifies climate change challenges in global centers of influence and calls for a “whole of government approach” in managing those challenges.⁴² The QDR stipulates that DoD “must complete a comprehensive assessment of all installations to assess the potential impacts of climate change on its missions and adapt as required.”⁴³ DoD’s first department-wide sustainability plan states that one of four priority areas is to “maintain readiness in the face of climate change.”⁴⁴

To achieve these ends, multiple efforts are underway across DoD. The Strategic Environmental Research and Development Program (SERDP) is currently funding four research projects that are developing the understanding, models, and tools needed to assess the impacts of climate change at coastal military installations.⁴⁵ This research stipulated sea level rise scenarios ranging from 0.5 to 2 meters and not tied to any particular greenhouse gas scenario (SRES or RCP). Other SERDP projects are designed to improve our understanding of climate change impacts in the Southwest United States and in Alaska. SERDP expects to expand its analyses in the future to include Pacific island installations and other considerations.

To satisfy the need for credible climate change future scenarios and other information, SERDP participates in the NCA. This ensures coordination between SERDP research and the US Global Change Research Office. An interagency task force and a federal advisory committee (hosted within NOAA) guide the NCA; DoD participates in both. These interagency efforts facilitate DoD interaction with the federal science community and provide access to the current state of scientific information while reducing redundancy of effort.

The US Navy’s Task Force Climate Change (TFCC) produced a Navy Climate Change Roadmap⁴⁶

The national security community can access model results from three major efforts: NAS 2013/SRES A2 and B1/CMIP3, NAS 2013/SRES A2/RCCAP, and AR5/RCP/CMIP5.

⁴¹ Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson (eds.), *Global Climate Change Impacts in the United States* (Cambridge University Press, 2009).

⁴² White House, National Security Strategy (May 2010), at http://www.whitehouse.gov/sites/default/files/rss_viewer/national_security_strategy.pdf.

⁴³ *Quadrennial Defense Review Report*, p. 85.

⁴⁴ Department of Defense, *Strategic Sustainability Performance Plan FY 2010*, Public Version (August 26, 2010), at <http://www.denix.osd.mil/sustainability/upload/DoD-SSPP-PUBLIC-26Aug10.pdf>.

⁴⁵ Strategic Environmental Research and Development Program, “Climate Change,” at <http://www.serdp.org/Program-Areas/Resource-Conservation-and-Climate-Change/Climate-Change>.

and—because of the special challenge of new missions in the Arctic Ocean, where sea ice coverage is decreasing rapidly—a Navy Arctic Roadmap.⁴⁷ The *Navy Climate Change Roadmap* explicitly calls for cooperation with NOAA (among other agencies) to “identify required capabilities for assessing and predicting global environmental change” on “strategic (months-decades) scales.” The Navy Arctic Roadmap calls for “new

The Navy Climate Change Roadmap explicitly calls for cooperation with NOAA to “identify required capabilities for assessing and predicting global environmental change” on “strategic (months-decades) scales.”

capabilities that current technology may provide to reduce uncertainty in 10–30 year predictions of arctic ice coverage.” The Navy also participates in an “interagency partnership to develop and implement a Next Generation Numerical Environmental Prediction capability for coupled air-ocean-ice modeling.” The TFCC is likewise evaluating the potential for “developing a coupled, air-ocean-ice, single-km resolution, non-hydrostatic prediction capability suitable for the Arctic.”

NOAA’s National Climate Prediction and Projection (NCP) pilot platform supports approaches to develop, deliver, and facilitate use of regional climate information. It is a community enterprise where climate information users, infrastructure developers, and scientists come together in a collaborative problem-solving environment. The community focuses on synthesis of existing climate capabilities spread across federal agencies and many other sources.⁴⁸

In North Carolina, proposed legislation⁴⁹ would prohibit policy decisions based on the results of “climate change models.” If enacted, sea level rise estimates by state agencies would be based only on historic data and not model estimates that project much faster rates of sea level rise. This would result in inconsistent planning between state and federal agencies that exercise land management responsibilities in the same area (*Figure 4*).

Recommended actions

We propose a three-pronged approach to clarify the need for and value of authoritative actionable projections, addressing unique requirements of national security missions.

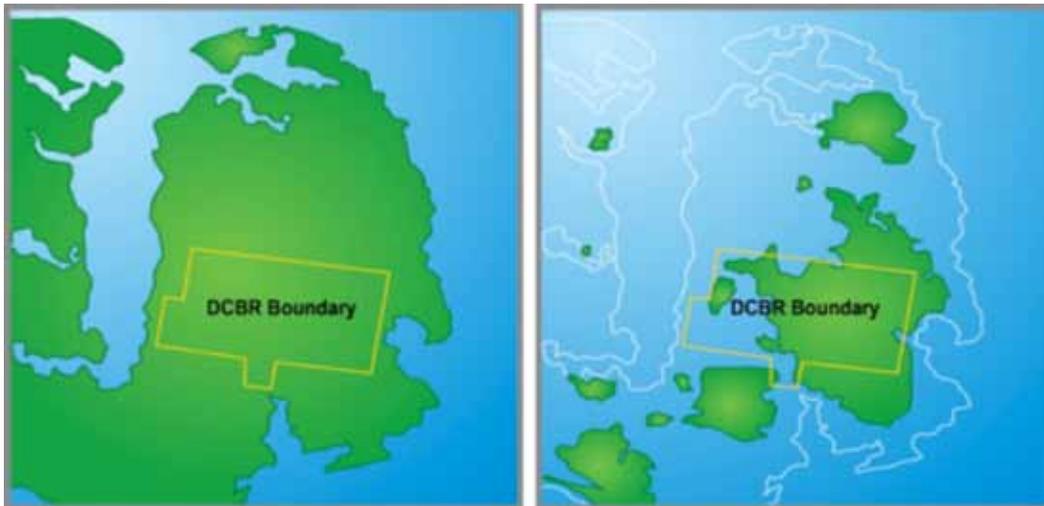
1. Develop a background paper on challenges and options for “official” predictions. This paper should consider the following questions, among others:
 - a. Does the national security community have a coordinated plan to access, evaluate, use, and continuously update climate change information?
 - b. What challenges are created by using research models (yielding projections, not predictions) for policy development?
 - c. Does the fact that many model results originate from other nations create concerns, particularly if such countries do

⁴⁶ US Navy, Task Force Climate Change, *U.S. Navy Climate Change Roadmap* (April 2010), at <http://www.navy.mil/navydata/documents/CCR.pdf>.

⁴⁷ US Navy, Task Force Climate Change, *U.S. Navy Arctic Roadmap* (October 2009), at http://www.navy.mil/navydata/documents/USN_artic_roadmap.pdf.

⁴⁸ Richard B. Rood, “National Climate Predictions and Projections Platform (NCP),” Briefing (n.d.), at http://www.cpc.ncep.noaa.gov/products/ctb/meetings/2011/CFsv3/Rood_NCPP.pdf.

⁴⁹ North Carolina General Assembly, House Bill 819/S.L. 2012-202, “Coastal Management Policies,” at <http://www.ncleg.net/gascrpts/BillLookUp/BillLookUp.pl?Session=2011&BillID=h819&submitButton=Go>.



*Figure 4. Projected change in coastline due to sea level rise at Dare County Bombing Range (DCBR) in North Carolina by 2100 (right panel) compared to today (left panel) based on the midrange IPCC A1B scenario. This work is based upon a DoD-funded study and adapted from U.S. Department of Defense, *Sea Level Rise Assessment for DoD Coastal Installations* (Source: http://www.dodworkshops.org/files/ClimateChange/Fact_Sheet_Sea_Level_Rise_Risk_Assessment_for_DoD_Coastal_Installations.pdf).*

This project presents sea level rise scenarios on North Carolina military installations in order to aid decision-making regarding management of natural resources and infrastructure for DoD facilities (Source: <http://www.denix.osd.mil/nr/OtherConservationTopicsAH/ClimateChange.cfm>, accessed July 6, 2012).

- not have agreements to exchange such information with the United States?⁵⁰
 - d. Does selection of models for analysis by the national security community require consideration of more criteria (perhaps related to national security) in addition to the “best available science”?
 - e. Is there a clear path to handling the uncertainty that is inherent in projections, compounded by imperfect models, and accentuated by the plethora of inconsistent model results?
 - f. What downscaling method should be used for national security analyses outside the United States and for more recent results that is analogous to the SRES-A2/RCCAP underway for DoD installations and missions?
2. Implement a work program to
 - a. explore DoD’s current use of climate projections and scenarios;
 - b. identify climate future and scenario needs and requirements unique to DoD’s mission; and

⁵⁰ Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3810.01C, “Meteorological and Oceanographic Operations (METOC),” paragraph 4, Policy, states that U.S. military METOC forces must be capable of functioning without substantive dependence or reliance on non-DoD data or support.

- c. brainstorm potential approaches and technical solutions.

Work sessions can provide a venue for climate service providers to determine which approaches and resources are appropriate for DoD needs.

3. Jointly develop a cooperative plan for official decadal predictions of climate that meet national security community needs and requirements. This joint effort should address the attendant uncertainty in model results.

Learning how to discuss these challenges and dealing with attendant uncertainty may represent the most significant opportunity yet to advance the process of decision making under uncertainty.

Relation to NOAA and NWS strategic planning

NOAA's Strategic Plan identifies climate adaptation as a key element of its first strategic goal. The actions we recommend are consistent with and support all four objectives under that strategic goal.

Most relevant is Objective 1: "Improved scientific understanding of the changing climate system and its impacts." NOAA's fourth strategic goal is to "Improve forecast skill to meet accuracy and confidence thresholds required for decision-making and risk management." This is precisely the step we recommend under Theme 2, although we recognize that the concept of "skill" in climate change must take a

different meaning than that traditionally applied by NWS for weather forecasts.

National Weather Service Strategic Goal 3 calls on NWS to "Improve and expand climate modeling for time scales from weeks and seasons to year." NWS Strategic Goal 5 seeks to "Enable integrated environmental forecast services supporting healthy communities and ecosystems." Our recommendations are consistent with both of those NWS Strategic Goals.

Payoff of improvements

Answers to the above questions affect the ability of the national security community to prepare for and respond to the challenges of climate change. Proposed steps would complement existing national defense efforts (for example, Section 2 of the *US Navy Climate Change Roadmap*).

Greater cooperation between the national security community and NOAA will address the challenges of moving from a research-based analysis of climate change possibilities to risk-based, vulnerability-based, and sustainable responses to climate change.

Learning how to discuss these challenges and dealing with attendant uncertainty may represent the most significant opportunity yet to advance the process of decision making under uncertainty.

Theme 3—Support National Security with NOAA Climate Products

Challenge

Although many climate products are available in the NOAA suite of products, NOAA and the national security community should enhance existing partnerships and form new ones to identify better opportunities for greater use of current observation, monitoring, and prediction climate products for the national security sector.

Context within the meeting

Workshop participants showed existing uses for products and noted that some NOAA climate products do not extend outside the United States. Many proposed national security uses require climate services for foreign regions. Although climate information at all spatial scales can be used for specific national security problems, there is a particular need for information at high spatial resolution. In addition, there is a need for reliable climate information at the extreme values of the distribution. The utility of information is currently limited due to several critical issues: access to climate data, scientific methodologies, and tested applications in na-

tional security sectors. The most common need that the participants expressed was for authoritative climate information of the kind that NOAA provides.

Context in the literature

The World Meteorological Organization (WMO) has identified global-scale long-lead forecast centers, including NCEP and CPC, that satisfy professional standards and minimum requirements.⁵¹ Each center provides products with lead times at least to 4 months, but longer term forecasts that would be of interest in this report are not required. The skill provided by decadal-range predictions is sufficient to begin international coordination in multi-annual-to-decadal prediction.⁵²

Evaluation of the first decade of long-lead NCEP and CPC official seasonal forecasts indicates significant skill in both temperature and precipitation forecasts issued 1 year in advance, although the skill can vary with season, spatial location, and existing climate signals. The CPC seasonal forecast uses several statistical and dynamic forecast tools (discussed below). Of these, NOAA's Climate Forecast System (CFS) offers the greatest potential for global capabilities.⁵³

Importance to national security

Long-lead climate forecasts (3 month and beyond) from NOAA could provide tools needed by the national security community to optimize performance, avoid hazards, or plan response. Applications could encompass operations of the players themselves, warning of affected communities, or preservation of entire countries.

⁵¹ World Meteorological Organization, "Global Producing Centres for Long Range Forecasts," at http://www.wmo.int/pages/prog/wcp/wcasp/clips/producers_forecasts.html.

⁵² R. J. Graham et al., "Long-Range Forecasting and the Global Framework for Climate Services," *Climate Research*, 47:1-2 (2011), pp. 47–55.

⁵³ R. Livezey, and M. Timofeyeva, "The First Decade of Long-Lead U.S. Seasonal Forecasts: Insights from a Skill Analysis," *Bulletin of the American Meteorological Society* 89 (2008), pp. 843–854.

NOAA is still evaluating the most recent operational CFS (version 2) to understand model-specific strengths, but available literature shows limited existing monthly skill (as opposed to seasonal average) beyond month 1.⁵⁴ After a lead time of approximately 30–40 days, the skill of monthly mean predictions from CFS is dominated by sea-surface temperature (SST) anomalies in the tropical central and eastern Pacific. Skillful prediction of monthly means may be limited by the inherent limits in predictability.⁵⁵

Status of federal and other efforts

One example of a long-lead forecast now used by the national security community is the food security outlook from the USAID Famine Ear-

ly Warning Systems Network (FEWS NET). The FEWS NET communication and decision support products help decision makers mitigate food insecurity for 25 countries in sub-Saharan Africa (*Figure 5*), Afghanistan, Central America, and Haiti.⁵⁶

The major long-lead product of FEWS NET is a map updated semi-annually showing projected food insecurity (at five levels) for a country using the estimated highest level of severity of food insecurity at a sub-national level.

FEWS NET is a collaborative effort of USAID, NOAA, USDA, the US Geological Survey (USGS) Earth Resources Observation and Science (EROS) Data Center, NASA, and Chemonics International. NOAA provides the necessary rainfall forecast.⁵⁷

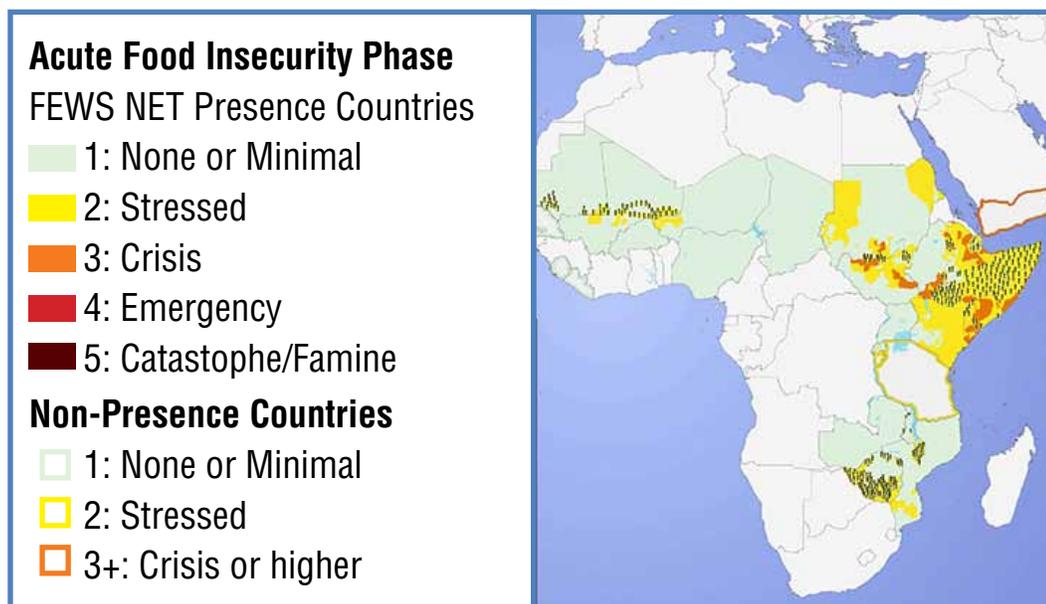


Figure 5. Example map output of FEWS NET showing the food security outlook for Africa for the fourth quarter of 2012 (October-December).

⁵⁴ Yuan Xing et al., “A First Look at Climate Forecast System Version 2 (CFSV2) for Hydrological Seasonal Prediction,” *Geophysical Research Letters* 38 (2011).

⁵⁵ A. Kumar, M. Y. Chen, and W. Q. Wang, “An Analysis of Prediction Skill of Monthly Mean Climate Variability,” *Climate Dynamics* 37:5-6 (2011), pp. 1119–1131.

⁵⁶ Famine Early Warning Systems Network, “Product Catalogue,” at <http://www.fews.net/ml/en/product/Pages/default.aspx>.

⁵⁷ US Geological Survey, “Project Overview,” at http://earlywarning.usgs.gov/fews/dp_overview.php.

NOAA's official suite of operational climate forecasts⁵⁸ consists of the following:

- 6–10 and 8–14 day outlooks released daily
- Tropical Pacific mean SST outlook (Niño 3.4 area)
- 1-month outlook available at half-month lead
- 3-month outlooks available at 1-month steps for 13 leads: from one-half to 12.5 months into the future
- Drought outlooks released monthly for a period of 3.5 months
- Hurricane seasonal outlooks for the Atlantic and eastern Pacific
- Global tropics hazards and benefits outlook.

Roles and responsibilities for official NOAA climate products are distributed across several organizations within NOAA.⁵⁹

Global climate forecast products⁶⁰ are available at the CPC international desks.⁶¹ Although only African rainfall outlooks are currently available at seasonal scale (*Figure 6*), many existing global products might be useful to the national security community, like in the FEWS NET example described above. The African desk operational forecast has been available since 1996. These products have been developed to support NOAA's international climate activities and meteorological institutions from developing countries. The long operational history of these products

confirms their reliability (owing to demonstrated skill). Targeted applications for national security needs might require leveraging existing or developing new partnerships with NOAA to specify new requirements for the operational products.

DoD and other national security groups are not involved in NCPP (described in Theme 2) through a memorandum of understanding (MOU). NCPP therefore provides an opportunity for greater collaboration.

Recommended actions

To understand the current and potential coverage of climate products and which ones can meet national security needs, we recommend four complementary activities:

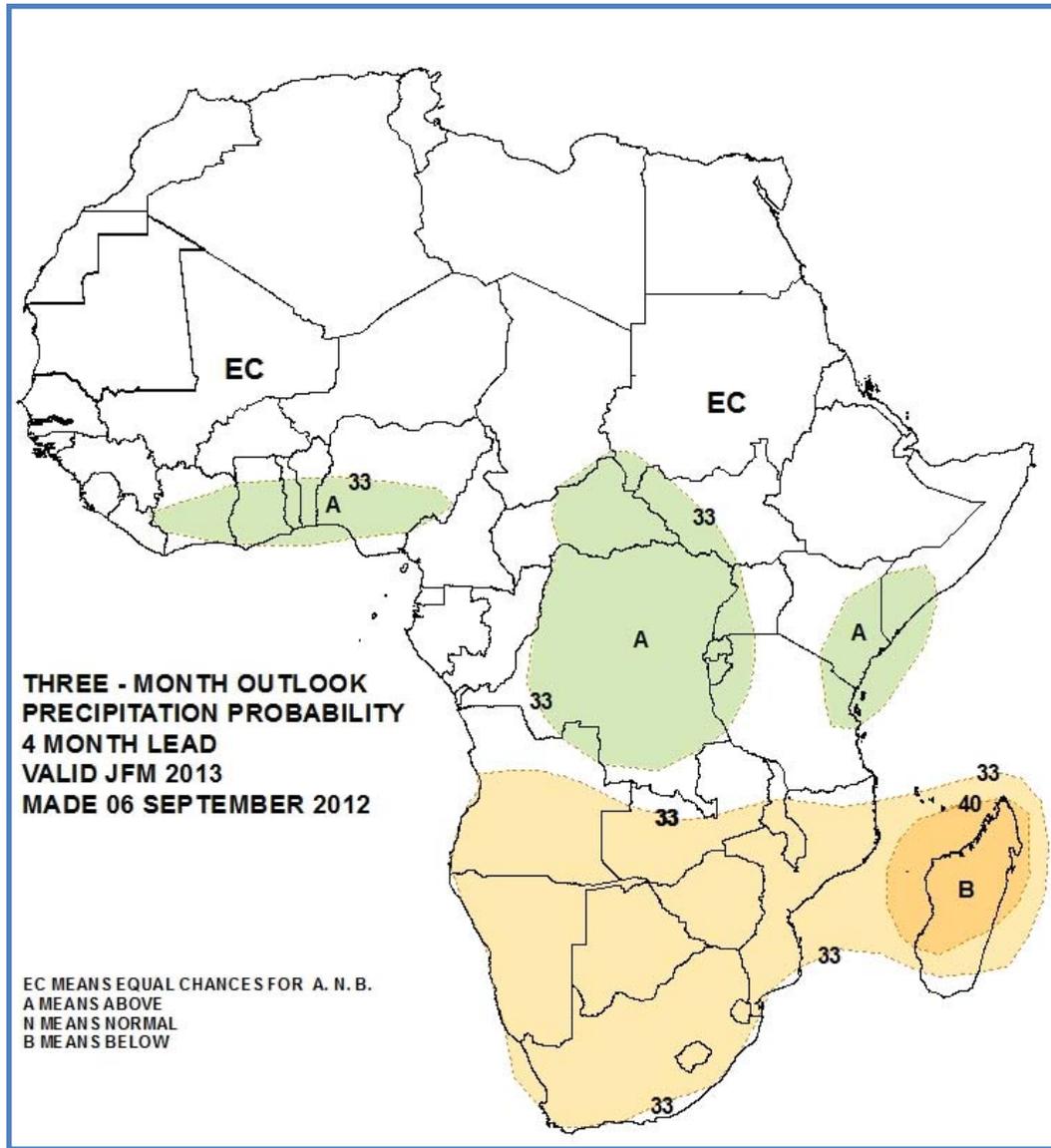
1. Develop a concise climate variability and climate change vocabulary and product fact sheet, including product examples distinguishing predictive versus projection products, skill, uncertainty, current coverage (time and space), possible extent, and level of investment needed.
2. Based on the fact sheet described above, and in light of climate service products already in use within the national security community, brainstorm the potential use of existing climate service products. Engagement with national security technical collaborators can help match current products with emerging applications and new partners, and identify spatial coverage and timescale gaps related to user community

⁵⁸ Official operational climate forecasts are specified, defined, and identified in National Weather Service Instruction 10-1001, "Operations and Services, Climate Services, NWSPD 10-10, Climate Outlooks" (October 31, 2011), at <http://www.nws.noaa.gov/directives/sym/pd01010001curr.pdf>.

⁵⁹ National Weather Service Policy Directive 10-10, "Operations and Services, Climate Services" (November 18, 2009), at <http://www.nws.noaa.gov/directives/sym/pd01010curr.pdf>.

⁶⁰ By this we mean these products whose coverage extends outside of US boundaries. They are not included in the list of official operational products, although they are operational.

⁶¹ NWS, "Climate Prediction Center—International Desks," at http://www.cpc.ncep.noaa.gov/products/african_desk/cpc_intl/index.shtml.



Source: http://www.cpc.ncep.noaa.gov/products/african_desk/cpc_intl/africa/cons_fcsts/africafcst_cons_201209.pdf.

Figure 6. Example of CPC African Rainfall Outlooks for January 2013 to March 2013.

needs.⁶² Formal and informal interactions can improve the use of existing products.

3. Consider the potential of extending existing products or creating new products. Prioritize efforts and plan to implement such extensions.
4. National security agencies can consider joining NOAA in NCPP through an existing or new MOU.

Relation to NOAA and NWS strategic planning

NOAA's Strategic Plan calls for "integrated services meeting the evolving demands of regional stakeholders" under its goal for enterprise-wide capabilities. The actions we recommend are consistent with that strategic goal. The NWS Strategic Plan calls on the NWS to "make small changes in NWS products and services to increase their usefulness by better understanding the needs of

new partners," particularly in "sectors that underutilize our current and potential information" Our recommendations are consistent with that NWS strategy.

Payoff of improvements

FEWS NET demonstrates one application of long-range forecasts of precipitation. Similar long-range forecasts of famine and other climate challenges could be applied in other areas. Long-range forecasts of precipitation can inform estimates of mobility on roads, functioning of river crossings, water availability for health, cooling needs, and for operational support. Long-range forecasts of temperature can inform plans concerning personnel effectiveness. In the global context, long-range forecasts of temperature and precipitation can inform estimates of trade flows, logistics needs, and economic wellbeing.

Long-range forecasts of precipitation can inform estimates of mobility on roads, functioning of river crossings, water availability for health, cooling needs, and for operational support.

⁶² A useful example of data product challenges and application needs is in Shoichiro Miyawaki et al., "2 Weeks Ahead Temperature Prediction for Rice Crops," Session 2: Agriculture and Food Security, 10th Climate Prediction Applications Workshop, Miami, FL (March 13, 2012).

Theme 4—Move from Data Access to Data Application

Challenge

NOAA and other federal agencies maintain climate data that provide the foundation of climate services. Yet diverse formats, limited data access, management challenges, and dissemination of these massive data sets are significant barriers to research, product development, and application.⁶³ Taken together, these challenges suggest the need for a paradigm shift that reduces time spent accessing data and moves the emphasis to greater analysis and application. These challenges are more acute for national security practitioners, largely due to metadata transparency and IT security barriers.

Context within meeting

Three key points, related to issues of data access and application, arose during the workshop.

Users of NOAA climate services and products have experienced challenges with efficient and timely cross-network data sharing. These challenges arise directly from the fact that the users operate within the national security framework. In this case, concerns with computer system security prevent direct connection of secure servers of the national security community with public portals to NOAA servers where data reside. Examples demonstrated that the issue is common.⁶⁴

Those who provide NOAA climate products expressed concern that important metadata—some not official but representing the combined knowledge of the community of professionals who have labored over the years to create the products—are not captured with the products and may be lost to potential users.⁶⁵ Such metadata represent an opportunity for more effective application of these products.

...transfer-related security breaches represent the principal concern of the national security community when accessing climate data.

Importance to national security

Data security usually is ensured through encryption of data “at rest” and “in transit” using computationally secure cryptography. This aspect of data transfer is less problematic than the possibility that data transfers from open sources such as NCDC to secure systems make the latter open to attack from third parties. These transfer-related security breaches represent the principal concern of the national security community when accessing climate data.

Data systems related to national security are subject to rigorous restrictions to ensure data fidelity, operational integrity, and restricted access to sensitive compartmentalized information. Data transfers between NOAA servers and those of the national security community cannot rely on public systems. That limitation delays data application, leads to unproductive application of resources, and may impact operations. Conversely, unimpeded access between servers introduces unacceptable challenges to data system security. The massive quantities of data, particularly climate model results or remote sensing data, add additional challenges and further demonstrate the need for efficient access protocols.

⁶³ Defense Science Board, *Trends and Implications of Climate Change for National and International Security*, October 2011, www.acq.osd.mil/dsb/reports/ADA552760.pdf.

⁶⁴ We exclude examples at the request of participants.

⁶⁵ C. Ammann, “The Challenge of Managing Climate Vulnerability: From Apps to Scenario Theaters,” Session 7: National Security Case Studies, Tenth Climate Prediction Applications Workshop, Miami, FL (March 13–15, 2012).

Related to these issues, a direct result of both, and potentially inherent in the current structure of existing products, is the issue of the effort that data access demands under current data structure and organizational constraints. In general, the community of users will benefit from more efficient and effective access to NOAA climate products so that the amount of time spent on data access does not exceed 20 percent of the total project effort. The current thinking is that the

...climate information passes from the climate community to the synthesis and assessment community, and ultimately to decision makers, through two channels...Each of these...represents a potential opportunity for interdiction and disruption by third parties.

ratio of time for access versus for application may be 80:20 and the community should move to a model more like 20:80.⁶⁶ Moreover, that 80 percent should be thought of as data analysis, as well as other aspects of application.

Context in literature

The Defense Science Board describes a climate information system, in the context of a risk management system, that could meet national security needs.⁶⁷ Its report identifies multiple pathways in the climate information system linking researchers, models,

observations, climate data record production, decision support tools, and the decision-making community (Figure 7). In this model, climate information passes from the climate community to the synthesis and assessment community, and ultimately to decision makers, through

two channels: climate data record production, and decision support tools. Each of these pathways (arrows in Figure 7) represents a potential opportunity for interdiction and disruption by third parties. The DSB also identifies the “inactive research to operational pathway” as a barrier for these systems.

An example of current secure data access by the national security community to NOAA-provided data comes from monitoring space weather for potential disruption of electronic communications. The operational space weather community now has the capability to directly access the full set of Space Weather Prediction Center data on a secure server that bypasses the NOAA public website. This arrangement includes procedures to nominate members for access and approval processes within NOAA.⁶⁸

Status of federal and other efforts

The GridFTP data transfer protocol developed by the Globus project is one means for moving large files, such as those produced from climate models, over a wide-area network. It uses the Monitoring and Discovery System (MDS) for secure, fast (up to 1.55 Gb/second), and reliable access to NWS information, and Grid Security Infrastructure for authentication.⁶⁹ The security challenges of data exchange are well-recognized in the US national security community.⁷⁰

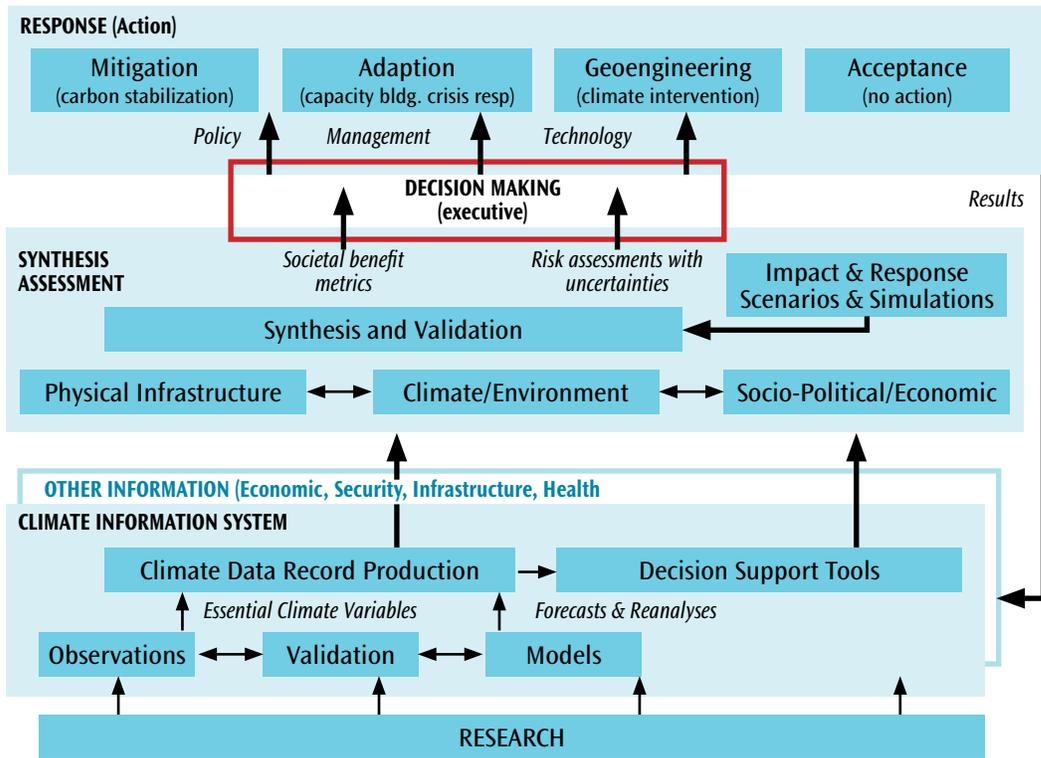
⁶⁶ C. Ammann, “The Challenge of Managing Climate Vulnerability: From Apps to Scenario Theaters,” Session 7: National Security Case Studies, Tenth Climate Prediction Applications Workshop, Miami, FL (March 13-15, 2012).

⁶⁷ Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Trends and Implications of Climate Change for National and International Security*, October 2011, at <http://www.acq.osd.mil/dsb/reports/ADA552760.pdf>.

⁶⁸ DOC/NOAA/NWS, “External Space Weather Data Store (E-SWDS) Program,” Briefing February 3, 2009, at http://www.spacewx.com/Docs/ESWDS_Program.pdf.

⁶⁹ W. Allcock et al., “Secure, Efficient Data Transport and Replica Management for High-Performance Data-Intensive Computing,” presented at Eighteenth IEEE Symposium on Mass Storage Systems and Technologies, 17-20 April, 2001. SC2001 November 2001, Denver. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&number=4022180&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxppls%2Fabs_all.jsp%3Farnumber%3D4022180.

⁷⁰ Charles Maney, “Security Issues When Data Traverses Information Domains: Do Guards Effectively Address the Problem?” May 18, 2004. SANS Institute. http://www.sans.org/reading_room/whitepapers/assurance/security-issues-data-traverses-information-domains-guards-effectively-address-problem_1418&ei=c5FnUN6iGoeY0QGhjoC4Cg&usg=AFQjCNH8Aoo7TeWkfwLhBAugR2UZPEmbXw.



Source: Riley Duren, Jet Propulsion Laboratory (Printed with permission).

Figure 7. Notional framework for implementing climate change risk management.
Adapted from Riley Duren, Jet Propulsion Laboratory.

Recommended actions

We recommend focused technical discussion on opportunities and means to improve data access, metadata transparency, and streamlined dissemination to better shift climate services staff time and resources to value-added data analysis and support for national security application users. Specific steps for the coming year include the following:

1. Convene a joint workshop to explore national security community climate data access barriers (interface, IT security, secure servers, etc.), metadata transparency needs, and streamlined dissemination opportunities, means, and best practices. Include representatives of elements of the national

security community that may require regular access to such data. Multiple potentially separate discussions may be needed, since different agencies may have different security limitations and concerns. Consider other examples where access to public portals with large data streams from secure servers is needed in the national security community as potential examples of systems that can provide useful solutions in this instance.

2. Brief these national security-oriented needs to the Interagency Climate Change Adaptation Task Force, and engage other national security agencies on barriers, needs, and opportunities to provide timely and efficient access to needed climate data and products.⁷¹ Develop a NOAA roadmap

⁷¹ NOAA/NWS/CPC and other CPASW 2012 participants presented several examples of portals and web-enabled tools that enable greater data access, efficiency, and transparency in obtaining climate data and climate variability products.

for realizing greater climate services data efficiency, cost savings, and national security user effectiveness.

Relation to NOAA and NWS strategic planning

Our recommendations are consistent with NOAA's Strategic Plan Goal 2 objective of a "more productive and efficient economy through environmental information relevant to key sectors of the US economy." Perhaps most relevant of the NOAA strategic goals is the enterprise-wide objective for a "modern IT infrastructure for a scientific enterprise." Such a modern IT infrastructure would provide for the secure access needs

we describe above. The actions we recommend are consistent with and support that objective.

NWS Strategic Goal 3 seeks to "enhance NWS services to support development and delivery of NOAA climate services." Our recommendations are consistent with that NWS strategic goal. Our recommendations are particularly relevant to NWS Strategic Goal 6, Objective 2: "Provide state-of-the-science, reliable, secure, and extensible infrastructure."

Payoff of improvements

Improved speed of access allows the US national security community to win the race to respond to climate challenges.

Theme 5—Sustain Cooperation

Challenge

Beyond short-term cooperation on specific and limited goals as detailed in themes 1–4, there is a larger opportunity for long-term cooperation that would continue to add value to national security operations.

Both military and intelligence operations regularly require action in the face of significant uncertainty; failure to act in the face of uncertainty can mean failure of the mission. The climate services community provides forecast products in which uncertainty can be great, but this uncertain information can still be actionable.

Context within meeting

Participants in the workshop reported multiple climate services relevant to the national security community and identified barriers and opportunities for better cooperation. The overarching concept—familiar to both communities, but not fully integrated into thinking at the nexus of these two—is that uncertain information is still actionable. Participants from the climate community widely acknowledged that climate products and services related to long-term projections (90 days to decades) carry large uncertainties. Nevertheless, the information can be very useful to the national security community. Participants from the national security commu-

nity demonstrated examples where such climate products already support operations despite their attendant uncertainty and called for more such products.

Context in literature

The national security community makes strategic and tactical decisions in a world dominated by uncertainty. General Gordon R. Sullivan (USA, Ret.) described the challenge this way: “If you wait until you have 100 percent certainty, something bad is going to happen on the battlefield.” Despite the challenges of uncertainty, the Center for Naval Analyses (CNA) recommends, “The national security implications of climate change should be fully integrated into national security and national defense strategies.”⁷²

The CNA report describes climate change as a “threat multiplier” and has called for sharing equipment, talent, and vast stores of data with climate scientists and cites the impact of declassified data on Arctic sea ice conditions as one example of the value of cooperation between the climate science community and the military. Vice Admiral Paul G. Gaffney (USN, Ret.) has said that civilian and military employees in the defense department have a responsibility to the nation to share their skills and information related to climate as long as security is not compromised.

The NRC has regularly updated our understanding of climate variability since at least 1995.⁷³

Information about future climate, despite uncertainty, can provide strategic advantage to those who use it.

Importance to national security

Information about future climate, despite uncertainty, can provide a strategic advantage to those who use it. It can prove a strategic deficit to those who do not. And it can tip the balance when opposing groups make different choices in its use.

⁷² Center for Naval Analyses, Military Advisory Board, *National Security and the Threat of Climate Change* (2007), at <http://www.cna.org/reports/climate>.

⁷³ National Research Council, Climate Research Committee, *Natural Climate Variability on Decade-to-Century Time Scales*, 1995.

The most recent update described how climate change may impact forecast verification, and discussed what adjustments may be needed in light of the “non-stationarity”⁷⁴ of climate. The NRC concluded that “long term trends associated with global warming and other alterations to the climate system (e.g., changes in land cover) demonstrate that the [traditional] requirements of stationarity are unlikely to be met for many time series of climate data.”⁷⁵ Related to these issues is the overall question of the stationarity of the climate record⁷⁶ and the implications for water resources management,⁷⁷ snowpack,⁷⁸ and food production.⁷⁹ Defense community interest in non-stationarity was demonstrated a decade ago.⁸⁰

Other peer-reviewed scientific literature examines whether recently observed extreme events could be predicted from the observational record.⁸¹ A related question is how long a record must be before one can demonstrate that new extremes

do not arise by chance.⁸² Climate scientists also consider specific influences on such extremes, such as how anomalies of sea surface temperature as observed in the Arctic Ocean may help predict future heat waves in Europe and Russia.⁸³ Rising temperatures will lead to higher operating costs and require adaptation in building designs at key US military installations.⁸⁴

Status of federal efforts

The 2010 National Security Strategy called for a “whole of government” approach using “all of the tools of American power ... [to] enhance international capacity to prevent conflict, spur economic growth, improve security, combat climate change, and address the challenges posed by weak and failing states.”⁸⁵ The 2010 QDR proposes an integrated approach to promoting stability.⁸⁶ The 2011 National Military Strategy takes a similar view.⁸⁷

⁷⁴ In a stationary time series, the population parameters such as mean and variance remain constant over time.

⁷⁵ National Research Council, Committee on Assessment of Intraseasonal to Interannual Climate Prediction and Predictability, *Assessment of Interseasonal to Interannual Climate Prediction and Predictability* (Washington, D.C.: National Academies Press, 2010), at http://www.nap.edu/openbook.php?record_id=12878.

⁷⁶ P. C. Milly et al., “Stationarity Is Dead: Whither Water Management?” *Science* 319 (2008), pp. 573–4.

⁷⁷ Cody L. Knutson, “The Role of Water Conservation in Drought Planning,” *Journal of Soil and Water Conservation*, 63:5 (September/October 2008), pp. 154A–160A.

⁷⁸ Gregory T. Pederson et al., “The Unusual Nature of Recent Snowpack Declines in the North American Cordillera,” *Science*, 333:6040 (July 15, 2011), pp. 332–335.

⁷⁹ Ana Iglesias, Sonia Quiroga, and Agustin Diz, “Looking Into the Future of Agriculture in a Changing Climate,” *European Review of Agricultural Economics*, 38:3 (2011), pp. 427–447.

⁸⁰ Peter Schwartz and Doug Randall, *An Abrupt Climate Change Scenario and Its Implications for United States National Security*, Global Business Network, October 2003; at <http://www.gbn.com/articles/pdfs/Abrupt%20Climate%20Change%20February%202004.pdf>. Reviewed in *Science*, 304:5669 (2004), p. 388.

⁸¹ R. Dole et al., “Was There a Basis for Anticipating the 2010 Russian Heat Wave?” *Geophysical Research Letters*, 38 (2011).

⁸² B. Liebmann et al., “Influence of Choice of Time Period on Global Surface Temperature Trend Estimates,” *Bulletin of the American Meteorological Society*, 91 (2010), pp. 1485–1491.

⁸³ J. Sedláček, O. Martius, and R. Knutti, “Influence of Subtropical and Polar Sea-Surface Temperature Anomalies on Temperatures in Eurasia,” *Geophysical Research Letters*, 38 (2011).

⁸⁴ R. Filadelfo et al., *Estimating Climate Change Effects on Installation Energy Use*, CNA Report DOP-2012-U-000800-Final, May 2012.

⁸⁵ 2010 *National Security Strategy*, p. 13.

⁸⁶ DoD, *Quadrennial Defense Review Report* (Washington, DC: DoD, February 2010), p. 13.

⁸⁷ DoD, *National Military Strategy of the United States* (Washington, DC: DoD, February 2011), p. 4.

The National Intelligence Council concluded that climate change could lead to low-level armed conflicts, particularly over water resources.⁸⁸ In 2010, the Director of National Intelligence testified that climate change would intensify challenges from water resources, natural disaster, and Arctic change and strain US military resources over the coming decades.⁸⁹ The 2010 Joint Operating Environment counts climate change (including its effect on coastal inundation and natural hazards) among 10 key trends that will impact US military forces.⁹⁰ *The Navy Climate Change Roadmap*⁹¹ calls for cooperation with the efforts of other US government agencies and the international community. Seeing the value of a “whole of government” approach, this roadmap specifically seeks to leverage NOAA’s climate services. Since 2008, US security interests in Africa, as identified by the Africa Command (USAFRICOM), includes climate-relevant considerations such as water availability, natural resource scarcity (and abundance), and climate change.

Climate scientists and national security professionals, especially at the federal level, are just beginning to learn each other’s needs. Much work remains to build a partnership.

Recommended actions

Sustained cooperation between the national security community and the climate services community could include these four actions:

1. Review the national security needs assessment; relevant strategies of the Office of the Secretary of Defense and military serv-

es, such as water security, etc.; and SERDP statements of need (in coordination with Theme 1).

2. Develop and annually update a climate services emerging application, maturity, and product list. This update should include the primary investigator, developing organization, topic, data coverage, current product extent, and technology readiness level.
3. Perform crosswalk analysis of emerging applications and mission needs. Test the ability of alternative tools to address the challenges identified.
4. Brief potential solutions and discuss next steps, funding, production, and deployment.

The Director of National Intelligence testified that climate change would intensify challenges from water resources, natural disaster, and Arctic change and strain US military resources over the coming decades.

Relation to NOAA and NWS strategic planning

Our recommendations are consistent with the enterprise-wide capabilities goals of the NOAA Strategic Plan to support “improved capacity to make scientifically informed environmental decisions” and for “integrated services meeting the evolving demands of regional stakeholders.” Our recommendations are also consistent with the Goal 2 objective of achieving a “more productive and efficient economy through environmental information relevant to key sectors of the US economy.”

⁸⁸ National Intelligence Council, *Global Trends 2025: A Transformed World* (Washington, D.C.: Government Printing Office, 2008), pp. 41, 54, 66.

⁸⁹ Dennis C. Blair, *Annual Threat Assessment of the US Intelligence Community for the Senate Select Committee on Intelligence*, February 2, 2010.

⁹⁰ US Joint Forces Command, *Joint Operating Environment 2010*, February 18, 2010, at http://www.jfcom.mil/newslink/storyarchive/2010/JOE_2010_o.pdf.

⁹¹ US Navy Task Force Climate Change, *U.S. Navy Climate Change Roadmap*.

Operations, plans, and analyses of the national security community will be more effective with awareness of the full range of elements that can benefit from climate services.

The NWS Strategic Goal 3 seeks to “enhance climate services to help communities, businesses, and governments understand and adapt to climate-related risks.” Our recommendations are consistent with that goal.

Payoff of improvements

Operations, plans, and analyses of the national security community will be more effective with awareness of the full range of elements that can

benefit from climate services. Continuous engagement can help to ensure that products and services are available when and where needed, and minimize surprise. Cooperation in testing alternative solutions to information needs can lead to more sophisticated understanding of issues involved in product applications and more appropriate choices of products for development. Regular interactions can help ensure effective operational use of appropriate products and reduce risks to those who support national defense.

Theme 6—Consider Emerging Product Areas

Challenge

Earth's climate is not static, and neither are the possible suites of climate services, applications, or products. Earlier themes discussed possible expansions of existing climate products and services. Theme 6 introduces a pipeline of new products. Engagement with specific user communities can yield early and continuing wins. These will reward cooperation and confirm the partnership.

Six climate products could support multiple elements of the national security community. Creating these products requires increasing levels of commitment. Products described here respond to specific challenges and can be implemented in a direct operational process once agreement is reached and funding secured.

Context within meeting

Challenges examined at CPASW 2012 offer rich opportunities for additional products that could be pursued further within the context of sustained engagement described under Theme 5. At least six possible products offer opportunities for progress:

1. **Permafrost**—Seasonal forecasts of active layer thickness in permafrost
2. **Tides**—Calculation of tidal extremes for scenarios of increased sea level
3. **Surges**—Coastal water level (surge) extremes correlated with ENSO events
4. **Health security**—Heat stress warning system related to specific activity regimes
5. **Regional climate variability**—Water resource cycles related to ENSO dynamics
6. **Food security**—Real-time weather products and seasonal crop yield projections.

These six products fall into three groups, representing three levels of effort. The first two can be implemented based on existing capabilities. These two can benefit from close collaboration between professionals at NOAA (CPC, NOS Coastal Services Center, National Snow and Ice Data Center, etc.), national security end users, and DoD technical experts such as those at the Army Corps of Engineers Cold Regions Research and Engineering Laboratory. We explore these two recommendations in detail below to demonstrate a joint approach for new products.

The third and fourth can be implemented in the medium term and mostly through continuing NOAA efforts described during the meeting. These products could find specific applications within the national security community and could benefit from focused engagement.

The last two items represent more significant investments that already involve many players and for which solutions have been sought for many years. Incremental advances in these can address significant issues in national security and are appropriate for continuing engagement between NOAA and the national security community as described in Theme 5.

Long-range forecasts of permafrost active layer thickness

Challenge

Permafrost in cold regions creates engineering and mobility challenges. Where ice within permafrost melts, these challenges are exaggerated. Temperature increases already observed in Alaska have disrupted structures and transportation, and these temperature increases (and attendant permafrost melting) are projected to accelerate in the future.

Context within meeting

One speaker at the workshop described challenges that permafrost processes pose to infrastructure in Alaska and how these challenges grow in importance as infrastructure such as pipelines expands and as climate continues to change in Alaska.⁹² She recommended that NOAA work with national security agencies to develop new forecast products to support infrastructure management and to warn of impending conditions that could disrupt infrastructure, transportation, and communication.

Context in literature

Permafrost underlies nearly all of Alaska, and the challenges it poses add significant design, construction, maintenance, and operation cost to engineered structures. When permafrost or the active layer above it melts, whether seasonally at the surface during the summer or in re-

sponse to warming climate, engineering problems are manifold. This problem is more likely in areas of discontinuous permafrost, such as much of southern Alaska, where ground surface temperatures are greater than -2°C . Melted permafrost loses structural stability, disrupting infrastructure anchored within it. The effect increases with greater volume of interstitial ice; volumetric loss during melting leads to settlement and destabilizes structures. Thawing permafrost could increase repair costs for public infrastructure by billions of dollars.⁹³

Active layer thickness (ALT)⁹⁴ affects engineering stability and varies with the ground temperature regime. Multiple factors affect ALT, including soil type, thickness, and moisture content; slope azimuth and declivity; cloudiness; and vegetative cover.⁹⁵ Physically based geographically detailed models can calculate the multiple controls on ALT and other relevant parameters.⁹⁶

Importance to national security

The Department of Defense operates seven installations in Alaska, including Joint Base Elmendorf-Richardson, Fort Wainwright, Eielson Air Force Base, and Fort Greely. All are within areas of permafrost. Other national security facilities include the North Warning System for ballistic missiles and Coast Guard stations.

Virtually all infrastructure in permafrost is at risk from reactivation of permafrost, and mobility is also hindered by related disruptions of transportation and communication infrastructure (Figure 8). Remobilization of permafrost may seriously impair energy supplies and development of energy projects. Hundreds of thousands of miles of pipelines and tens of thousands of wells operate in permafrost areas. Expanding drilling and production facilities into offshore regions rich in resources adds a new source of vulnerability and requires new information to characterize risk.

⁹² R. Jonassen, "Projecting the Sensitivity of Energy Projects to Warming in Northern Latitudes," Session 8: National Security Plenary Session, 10th Climate Prediction Applications Workshop, Miami FL, (March 13–15, 2012).

⁹³ P. H. Larsen et al., "Estimating Future Costs for Alaska Public Infrastructure at Risk From Climate Change," *Global Environmental Change*, 18:3 (2008), pp. 442–457; US Arctic Research Commission, Permafrost Task Force, *Climate Change, Permafrost, and Impacts on Civil Infrastructure*, Special Report 01-03 (Arlington, VA, 2003).

⁹⁴ The active layer is the portion of ground above the permafrost that thaws during the summer and refreezes during the winter.

⁹⁵ Y. L. Shur and M. T. Jorgenson, "Patterns of Permafrost Formation and Degradation in Relation to Climate and Ecosystems," *Permafrost and Periglacial Processes* 18:1 (January/March 2007), pp. 7–19.

⁹⁶ G. Tzipenko et al., "Spatially Distributed Model of Permafrost Dynamics in Alaska," *EOS Transactions of the American Geophysical Union*, 85:47 (2004), Fall Meeting Supplement, Abstract C12A-02.



Source: http://earthdata.nasa.gov/sites/default/files/styles/large/public/2005_permafrost_copper.jpg

Figure 8. Permafrost damage to Copper River and Northwestern Railway in Alaska.

Such calculations are reported for conditions of climate change in Alaska based on multiple alternative scenarios of climate change but are not performed for regular forecasts of ALT under current conditions of seasonal variability or to represent longer scale variations in Alaska climate.⁹⁷ One example of such a model was developed at the Geophysical Institute Permafrost Laboratory (GIPL) in Alaska. Several versions of that model are now in use; a recent version is GIPL2.⁹⁸

Status of federal and other efforts

Since early 2009, the executive branch has called for focused attention on the national security importance of warming-induced changes in the Arctic.⁹⁹ Multiple organizations support research on the thermal state of permafrost in Alaska and worldwide. The Interagency Arctic Research Policy Committee, housed in the White House

Office of Science and Technology Policy (OSTP), coordinates the research of 14 federal agencies.

They include the National Science Foundation (particularly the Office of Polar Programs), NOAA (particularly the National Snow and Ice Data Center), the US Army Corps of Engineers (especially the Cold Regions Research and Engineering Laboratory, CRREL), NASA (with a focus on applications of remote sensing), and the US Geological Survey (particularly the Alaska Science Center). The State of Alaska also funds research and monitoring of permafrost and maintains engineering capabilities for permafrost terrain. During the International Polar Year (2007–2009), multiple new research projects began in Alaska and other Arctic settings.

Virtually all infrastructure in permafrost is at risk from reactivation of permafrost, and mobility is also hindered by related disruptions of transportation and communication infrastructure.

⁹⁷ University of Alaska Fairbanks, “SNAP—Scenarios Network for Alaska & Arctic Planning,” <http://www.snap.uaf.edu/>.

⁹⁸ University of Colorado at Boulder, Community Surface Dynamics Modeling System (CSDMS), “Numerical Modeling of Permafrost Dynamics in Alaska using a High Spatial Resolution Dataset,” at http://csdms.colorado.edu/wiki/HPCProjects:Numerical_Modeling_of_Permafrost_Dynamics_in_Alaska_using_a_High_Spatial_Resolution_Dataset.

⁹⁹ National Security Presidential Directive (NSPD 66)/Homeland Security Presidential Directive (HSPD 25), January 9, 2009.

NOAA's Arctic strategy recognizes the importance of permafrost as a repository for methane (a potent greenhouse gas) threatened by global warming and expresses the need for "predicting impacts caused by a changing Arctic," including those due to melting permafrost on infrastructure, petroleum resource exploration, and coastal erosion. The NOAA plan calls for an engagement strategy for collaboration with other federal agencies on these challenges.¹⁰⁰

Recommended actions

Forecasts of ALT up to 1 year in advance using an existing permafrost model such as GIPL2 would represent a new product and could serve multiple user communities, including the national security community. Such a system might be implemented by CRREL. NOAA would provide results from existing forecast systems and work with CRREL to make sure climate forecasts are applied correctly.

Immediate steps to address this opportunity include the following:

1. Document the magnitude of the permafrost challenge, potential solutions, and existing programs and scientists that can contribute to the solution.
2. Convene relevant personnel from NOAA, other relevant national science organizations, and the national security community to develop a detailed plan for implementation.

Relation to NOAA and NWS strategic planning

Our recommendations for forecasts about seasonal permafrost activity are consistent with

Goal 1 (climate adaptation) of the NOAA Strategic Plan to support "improved capacity to make scientifically informed environmental decisions" and "integrated services meeting the evolving demands of regional stakeholders." Our recommendations are also consistent with the science and technology enterprise objectives for "accurate and reliable data from sustained and integrated Earth observing systems" and "an integrated environmental modeling system." These recommendations are also consistent with the objective of achieving an "improved understanding of ecosystems to inform resource management decisions."

The NWS Strategic Goal 5 seeks to "enable integrated environmental forecast services supporting healthy communities and ecosystems." Our recommendations are consistent with that goal also.

Payoff of improvements

Forewarning of the extent of melting of the active layer can allow those who must respond to infrastructure damage an opportunity to plan response, position resources, and prepare for action. Such forewarning can also allow those planning mobile operations to foresee and avert risks. Advance notice of potential disruptions in oil pipeline systems may allow stockpiling reserves so that refinery operations are not interrupted.

Increased awareness, operational integration, and success will foster further opportunities to prepare for greater challenges from permafrost changes under climate change throughout the Arctic and beyond.

¹⁰⁰ "NOAA's Arctic Vision and Strategy," February 2011. http://www.arctic.noaa.gov/docs/NOAAArctic_V_S_2011.pdf.

Long-range tidal extreme forecasts

Challenge

Observational records demonstrate increases in the sea level during the past 100 years, and long-term climate change projections suggest that the sea level could rise 1 meter or more in the coming century. Sea level rise directly threatens coastal installations and operations and indirectly increases risk from higher storm surge during extreme events. A more subtle effect is less understood and is not included in many analyses of sea level rise and storm surge: namely, that a higher sea level exerts a non-linear effect on tidal extremes. This effect could increase risk in coastal settings.

Context within meeting

One speaker at the workshop presented results of a study of the vulnerability to climate change

of Naval Station Norfolk.¹⁰¹ The analysis considered multiple factors, one of which was a worst-case scenario combining a storm surge during a hurricane with a high perigeon spring tide. Although the storm surge was calibrated to represent a greater intensity storm, and the scenario included the effect of sea level rise, the tidal extreme was based upon historical records and amplitude models calibrated to present conditions.

Context in literature

The literature on expected tidal extremes under conditions of climate change or climate variability is scanty; however, long-term observations demonstrate that changes in tidal range at a single location do occur.¹⁰² Some evidence of past changes in tidal range comes from studies of paleo-oceanography

An increase in tidal range of 10 centimeters, coupled with worst-case storms, could significantly increase inundation risk at naval stations around the world.

Importance to national security

Naval Station Norfolk and other naval stations around the world lie close to sea level, and major parts of such installations are within 1–2 meters of the mean high tide. An increase in tidal range of 10 centimeters, coupled with worst-case storms, could significantly increase inundation risk at these locations.¹⁰³ Other facilities are more vulnerable to inundation than Naval Station Norfolk.

In areas of large tidal range, strong barotropic tidal currents are hazards to navigation, including boils, eddies, whirlpools, and changing directions of ebb and flow tides.¹⁰⁴ Baroclinic waves associated with tides affect acoustics and other underwater operations. Water height variations influence other naval operations such as amphibious landings, search and rescue, docking, and mine drift. Tidal currents also affect sedimentation in channels, flooding, dispersal of pollutants, marsh restoration, and construction of piers.¹⁰⁵

¹⁰¹ K. Burks-Copes and E. Russo, “Quantifying Risks of Climate Change and Sea Level Rise to Naval Station Norfolk, Session 6: National Security Plenary Session, 10th Climate Prediction Applications Workshop, Miami, FL (March 14, 2012).

¹⁰² P. L. Woodworth, “High Waters at Liverpool Since 1768: The UK’s Longest Sea Level Record,” *Geophysical Research Letters* 26 (1999), pp. 1589–1592.

¹⁰³ R. A. Flather, “Tidal Range and Storm Surges,” in *Global Warming and Climate Change*, Seminar Report of the Irish Sea Forum, University of Liverpool, April 26, 1992 (Liverpool: Liverpool University Press, 1992), pp. 29–40.

¹⁰⁴ See, for example, Federal Highway Administration, “HEC 25—Tidal Hydrology, Hydraulics, and Scour at Bridges,” Chapter 2—Tidal Hydrology and Boundary Conditions, at <http://www.fhwa.dot.gov/engineering/hydraulics/hydrology/hec25c2.cfm>.

¹⁰⁵ Naval Postgraduate School, Department of Oceanography, “Basic Concepts in Physical Oceanography: Tides,” <http://www.oc.nps.edu/nom/day1/partc.html>.

and paleoclimatology. On millennial scales, sea level and basin morphology affect tides.¹⁰⁶ Increasing trends along the East Coast differ by site, and in some places mean higher high water is rising faster than mean high water, suggesting increasing tidal range.¹⁰⁷ Anomalies of 2.76 to 7.38 millimeters per year at five stations along the Northeast Coast of the United States arise from trends in tides not accounted for by the National Ocean Survey tidal model.¹⁰⁸

Tides may be computed using either tidal prediction (superposition of harmonics derived from observational records) or from hydrodynamic models (tidal simulation). Each has its limitations. Both report tides relative to the National Tidal Datum Epoch (NTDE). The present NTDE is 1983 through 2001. Tidal prediction is limited to locations with observations, usually from tidal gauges, and assumes a stationary record. Hydrodynamic models must be constrained with boundary conditions from global models, which cannot represent complex coastlines such as the mouth of the Chesapeake Bay.¹⁰⁹

Tidal range today varies from about 1 foot to 19 feet (Eastport, ME) on the Eastern Seaboard, and it exceeds 30 feet in parts of Alaska. In some settings such as the Penobscot River in Maine, tidal range increases upriver (11.8 feet at the mouth to a maximum of 15.5 feet at Bangor).¹¹⁰ If this difference is magnified as sea level rises, the impacts could be important.

Multiple factors influence tidal range, including ocean size, coastal configuration, depth of water, profile of the sea floor, and orbital configuration relative to the moon and sun (the influence of other planets is usually ignored).¹¹¹ Changes in water depth can change the tidal wavelength and the propagation and dissipation of tidal energy.¹¹² Tides are amplified in shallow seas where the natural mode of resonance of the area matches a harmonic of the tide. The most dramatic example is the Bay of Fundy (38.4-foot mean tidal range), whose dimensions are about one-fourth the wavelength of the tide. Tidal constituents¹¹³ lose energy through friction with the bottom and transfer energy to other harmonics

¹⁰⁶ I. Shennan et al., "Modelling Western North Sea Palaeogeographies and Tidal Changes During the Holocene," in I. Shennan and J. Andrews (eds.), *Holocene Land-Ocean Interaction and Environmental Change around the North Sea*, Geological Society, London, Special Publications, 166 (2000), pp. 299–319.

¹⁰⁷ R. Flick, J. Murray, and L. Ewing, "Trends in United States Tidal Datum Statistics and Tide Range," *ASCE Journal of Waterway, Port, Coastal and Ocean Engineering*, 129:4 (2003), pp. 155–164.

¹⁰⁸ Paul Kirshen et al., Coastal Flooding in the Northeastern United States Due to Climate Change," in *Mitigation and Adaptation Strategies for Global Change*, 13:5 (2008), pp. 437–451.

¹⁰⁹ K. L. McInnes, J. G. O'Grady, and I. Macadam, *The Effect of Climate Change on Extreme Sea Levels in Port Phillip Bay*, Report to the Victorian Department of Sustainability and Environment (State Government of Victoria, Australia, 2009), at <http://www.climatechange.vic.gov.au/futurecoasts>.

¹¹⁰ NOAA, Center for Operational Oceanographic Products and Services, "Tides and Currents," <http://tidesandcurrents.noaa.gov>.

¹¹¹ D. T. Pugh, *Tides, Surges, and Mean Sea-Level* (John Wiley and Sons, 1987).

¹¹² R.A. Flather and J. A. Williams, 2000. "Climate Change Effects on Storm Surges: Methodologies and Results," in J. Beersma et al. (eds.), *Climate Scenarios for Water-Related and Coastal Impact*, ECLAT-2 KNMI Workshop Report No. 3, Royal Netherlands Meteorological Institute (KNMI), the Netherlands (May 10–12, 2000), at http://www.knmi.nl/~beersma/paper_flather.pdf.

¹¹³ Each component of the tide is described by a particular amplitude and phase, which contributes to the total tidal signal. The main tidal constituent is the lunar semi-diurnal (half daily) or M2 tide, which has a period of 12.42 hours. Other lunar semidiurnal constituents are the N2, S2, and K2, with periods of 12.60, 12.00, and 11.97 hours, respectively. The diurnal (daily) constituents O1, P1, and K1 have periods of 25.82, 24.07, and 23.93 hours, respectively. Contributions to tides also occur on fortnightly, monthly, semi-annual, and annual time scales. The total height of the tide can be calculated by summing the contributions from the various constituents (harmonic superposition).

by non-linear processes.¹¹⁴ Because of this non-linear behavior, tidal range may increase or decrease as sea level rises. For example, *Figure 9* shows computed changes in the North Sea mean high water due to a rise in mean sea level of 50 centimeters. Note that mean high water is not the extreme rise that planners must consider at a naval facility, but this figure does demonstrate how tidal range will change in a complex way as sea level rises.

The effect of changes in coastal configuration upon future tidal extremes is far less certain and less predictable. Coastal configuration is also dynamic, in both the short and long term. In the

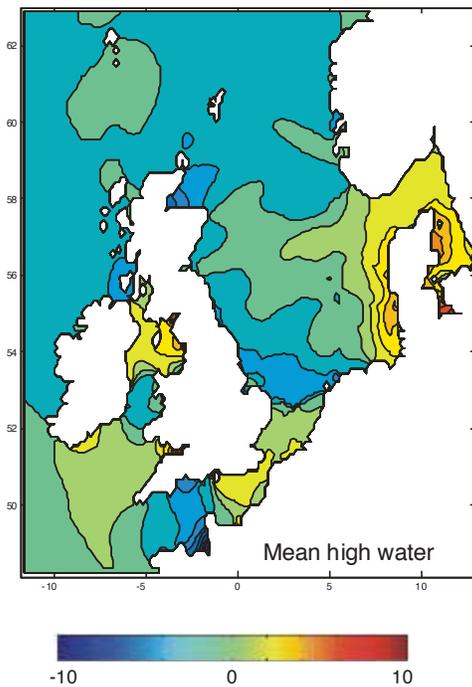


Figure 9. Change in mean tide in the North Sea from a sea level rise of 50 centimeters.¹¹⁵

short term, reconfiguration of coastline occurs regularly with both normal and storm-related erosion and deposition. In the long term, coastal configuration will change continuously and sporadically as sea level rise inundates coastal areas differentially; due to the cumulative effects of normal storm and other erosion processes; and due to the enhanced effect (if any) of greater storm frequency or intensity, or changes in the spectrum of storm events and resulting changes in sediment dynamics.¹¹⁶

Status of federal and other efforts

Two organizations share roles in determining tidal ranges: the National Ocean Service and the Naval Oceanographic Office.

The National Oceanic and Atmospheric Administration/National Ocean Service (NOAA/NOS) Center for Operational Oceanographic Products and Services (CO-OPS) maintains a Tides and Current web site with tidal predictions for about 3,000 reference and subordinate stations along US coasts and some international sites. CO-OPS also provides tidal models for about 700 sites, including 250 reference stations, tide prediction accuracy tables, observed long-term trends in sea level, and tide charts for some locations.¹¹⁷ Both the Federal Emergency Management Agency and the US Army Corps of Engineers use the NOAA tidal predictions to calculate and report expected coastal flood heights (including the effects of storm surge) with return periods of 10, 50, and 100 years. NASA provides satellite data useful to calibrate and test the NOAA tidal models.

¹¹⁴ G.D. Egbert and R.D. Ray, "Significant Dissipation of Tidal Energy in the Deep Ocean Inferred From Satellite Altimeter Data," *Nature*, 405 (2000), pp. 775-778.

¹¹⁵ R.A. Flather and J. A. Williams, 2000. "Climate Change Effects on Storm Surges: Methodologies and Results," in J. Beersma et al. (eds.), *Climate Scenarios for Water-Related and Coastal Impact*, ECLAT-2 KNMI Workshop Report No. 3, Royal Netherlands Meteorological Institute (KNMI), the Netherlands (May 10–12, 2000), at http://www.knmi.nl/~beersma/paper_flather.pdf.

¹¹⁶ R.A. Warrick, E.M. Barrow, and T.M.L. Wigley, *Climate and Sea Level Change: Observations, Projections and Implications* (Cambridge University Press, 2009).

¹¹⁷ NOAA, "Tides and Currents."

Navy oceanography products are distributed through several Naval Meteorology and Oceanography Command (NMOC) offices, including the Naval Oceanography Operations Command (NOOC), the Fleet Numerical Meteorology and Oceanography Center (FNMOC), and the Naval Oceanographic Office (NAVO). NOOC advises Navy operations on the operational impact of ocean and atmospheric conditions. The FNMOC weather forecast mapping model (WxMAP) includes swell and wind wave height, period, and direction with a 0.5-degree resolution. NAVO

Full determination of the effects of increased sea level upon tides will require significant computational capabilities, even for a single station and a single assumed sea level.

calculates tidal range for ports and other locations of interest to naval operations anywhere in the world. It operates 2D coastal circulation models (e.g. HYDROMAP, PC-Tides, AD-CIRC) that calculate tidal influences.

Recommended actions

Although calculating the effects of sea level rise on some terms of the quasi-empirical tidal equations is relatively simple, determining the effects of coastal configuration is extremely difficult and usually empirically based.¹¹⁸

Full determination of the effects of increased sea level upon tides will require significant computational capabilities, even for a single station and a single assumed sea level. Because the sea level must be associated with a specific time in order to calculate the astronomical terms, these calculations must be based upon a specific GCM result tied to a particular global change scenario (such as IPCC A1FI) or representative concentration pathway (RCP).¹¹⁹ This further complicates the effort and expands the complexity of considerations.

Full determination of the effects of increased sea level upon tides will require significant computational capabilities, even for a single station and a single assumed sea level. Because the sea level must be associated with a specific time in order to calculate the astronomical terms, these calculations must be based upon a specific GCM result tied to a particular global change scenario (such as IPCC A1FI) or representative concentration pathway (RCP).¹¹⁹ This further complicates the effort and expands the complexity of considerations.

The large number of combinations of cases means that a classification scheme must be developed to simplify the complexity of data input to analyses such as those performed under SERDP-funded research at Naval Station Norfolk. This classification scheme must pass scientific review before it can be used, and the effort to include this new factor into the analysis requires careful consideration.

In light of these challenges and NOAA's direct responsibilities in the realm of tidal forecasts, we recommend taking the following steps within the coming year:

1. Document the validity of the need for long-term tidal forecasts, areas, and time periods for which such information might be useful, and existing programs and scientists that can contribute to the solution.
2. Convene relevant personnel identified in step 1 to develop a detailed plan for implementation.

Relation to NOAA and NWS strategic planning

Our recommendations for long-range forecasts of tidal activity are consistent with Goal 1 (climate adaptation) of the NOAA Strategic Plan to support “improved capacity to make scientifically informed environmental decisions” and “integrated services meeting the evolving demands of regional stakeholders.” Our recommendations are also consistent with all objectives of NOAA Goal 4 to achieve resilient coastal communities.

These recommendations are consistent with NWS Strategic Goal 5 to “enable integrated environmental forecast services supporting healthy communities and ecosystems.”

¹¹⁸ Paul Schureman, *Manual of Harmonic Analysis and Prediction of Tides*, US Department of Commerce, Coast and Geodetic Survey, Special Publication No. 98 (Washington, D.C.: US Government Printing Office, 1958, reprinted May 1988).

¹¹⁹ M. Meinshausen et al. “The RCP Greenhouse Gas Concentrations and their extension from 1765 to 2500” (2011), *Climatic Change* (Special Issue on RCPs).

Payoff of improvements

Better information about how high tide extremes may change due to climate variability or as the sea level rises in response to climate change will help us better understand the risks posed to national security infrastructure and operations. This information has much broader application, as well: it can inform risk (and vulnerability) analysis for any coastal structure or

operation. One particular application would be to clarify the challenges for near-coastal marine energy generating facilities, particularly those that rely on power generated from the tidal range (as opposed to the tidal stream). Extreme low (drain) tides affect naval operations in coastal settings when hull clearance is below the sounding datum of navigational charts.

Glossary¹²⁰

Climate change: A change in the state of the climate that can be identified (e.g., via statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.¹²¹

Climate projection: A projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/radiative-forcing scenario used, which are based on assumptions concerning, for example, future

socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Climate variability: Climate variability refers to variations in the mean state and other statistics—such as standard deviations, the occurrence of extremes, and so on—of the climate at all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). See also “climate change.”

Forecast/prediction: When a projection is branded “most likely,” it becomes a forecast or prediction. A forecast is often obtained using deterministic models, and possibly a set of these, outputs of which can enable some level of confidence to be attached to projections.¹²²

¹²⁰ All terms except “prediction” are from the “Glossary of Terms” in C. B. Field et al. (eds.), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC) (Cambridge University Press, 2012). This reference does not define “prediction” or “climate prediction.”

¹²¹ This definition differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

¹²² IPCC, Data Distribution Centre, “Definition of Terms Used Within the DDC Pages,” at http://www.ipcc-data.org/ddc_definitions.html.

Appendix A—Reviewers

The authors thank the following individuals as well as one anonymous reviewer for comments that helped improve the final version of this document. These reviews were performed over a 6-week period in July and August of 2012. The authors have made every effort to address all review comments, and we accept responsibility for any remaining errors. We invite reader response to this document.

David P. Brown, Ph.D.
Regional Climate Services Director
Southern Region
NOAA/NESDIS/NCDC
819 Taylor St., Room 10A05C
Fort Worth, TX 76102
david.p.brown@noaa.gov
817-978-1100 ext 158

Mike Halpert, Ph.D.
Deputy Director
NOAA
Climate Prediction Center
5830 University Research Ct
Room 3102
College Park, MD 20740
mike.halpert@noaa.gov
301-683-3427

Holly C. Hartmann, Ph.D.
Director
Arid Lands Information Center
University of Arizona
1955 E. Sixth St.
Tucson, AZ 85721
hollyoregon@juno.com
541-607-6722

Michelle D. Hawkins Aguilar, Ph.D.
Physical Scientist
NOAA/NWS/OCWWS/CSD
Climate Services Division

1325 East West Hwy
W/OS4 Room 13352
Silver Spring, MD 20910
Michelle.Hawkins@noaa.gov
301-713-1970 x134

Marina Timofeyeva, Ph.D.
Physical Scientist
NOAA/NWS/OCWWS/CSD
Climate Services Division
1325 East West Hwy
W/OS4 Room 13352
Silver Spring, MD 20910
Marina.Timofeyeva@noaa.gov
301-713-1970 x131

John White
Staff Weather Office
U.S. Army Special Operations Command
Fort Bragg, NC 28310
whitejoh@soc.mil
910-432-7940

Jiayu Zhou, Ph.D.
Physical Scientist
NOAA/NWS/OST/PPD/MOIB
Modeling and Observing Integration Branch
1325 East West Hwy
W/OST13 Room 15368
Silver Spring, MD 20910
jiayu.zhou@noaa.gov
301-713-3557 ext178

Appendix B—Biographies

Jeremy Alcorn

Jeremy M. Alcorn has an extensive background in environmental security, sustainability planning, and greenhouse gas accounting. Since January 2010, he has been a research consultant on the staff of LMI's Energy and Environment group. Before that, he was an environmental engineer at Concurrent Technologies Corporation, where he conducted the Army's first bottom-up greenhouse gas inventory at several installations. Mr. Alcorn also spent 6 years at Science Applications International Corporation, providing agency sustainability support to the National Aeronautics and Space Administration, Air Force, and Environmental Protection Agency. He has an MS in environmental science from George Mason University.

Rachael Jonassen

Rachael G. Jonassen, PhD, is an authority on climate change science. Before joining LMI's Energy and Environment group, she served as program director at the National Science Foundation, where she led the organization's carbon cycle research efforts for the U.S. Global Change Research Program. As a member of the interagency working group for the carbon cycle, she helped manage the first State of the Carbon Cycle Report, organized the first all-investigators meeting on the carbon cycle, and promoted international cooperation on bilateral climate change agreements. Dr. Jonassen was a lead author of *A Federal Leader's Guide to Climate Change: Policy, Adaptation, and Mitigation* (2009) and the *Strategic Plan for the U.S. Climate Change Science Program* (2003). She has a PhD in geology from The Pennsylvania State University.



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